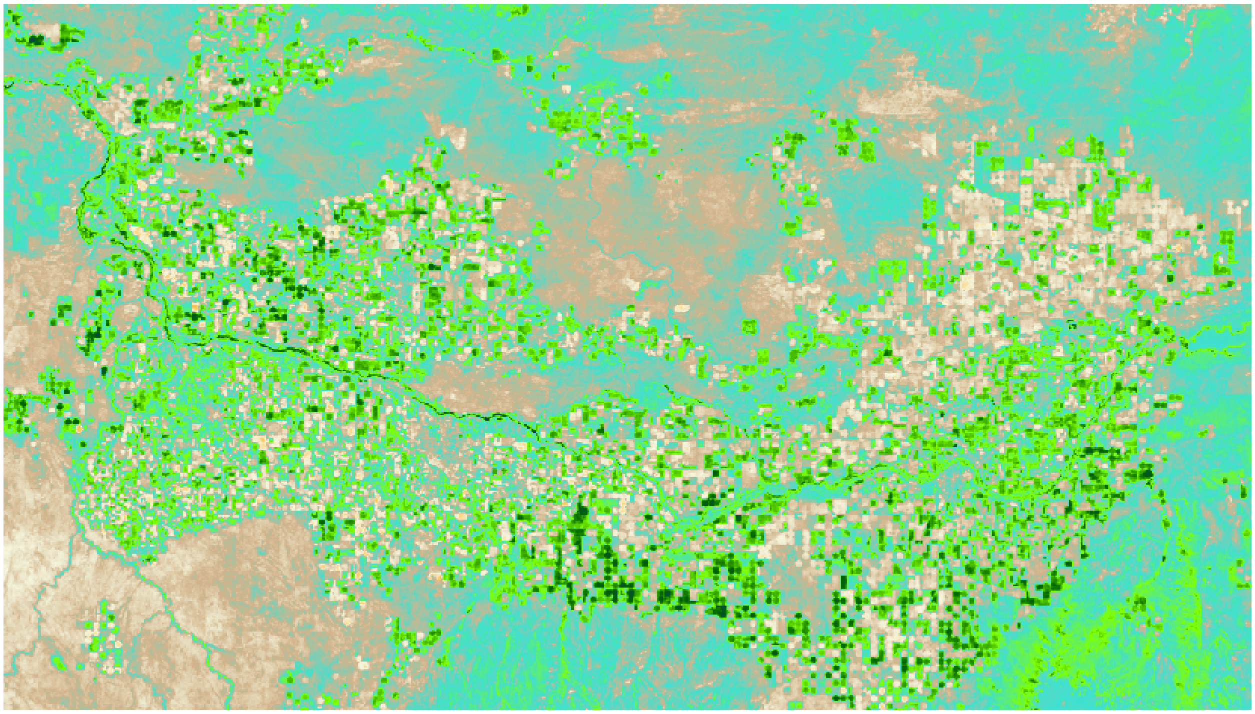
Report on the Production of Provisional Near-Real-Time and Final Evapotranspiration Maps using the METRIC^{tm} Model for the Eastern Snake Plain Region, Idaho April-October 2016 – Final Processing

submitted to
Idaho Department of Water Resources

by
Dr. Ricardo Trezza, C.W. Robison,
C. Kelly and Richard Allen
University of Idaho
Kimberly, Idaho



Final Report, January 31, 2017

Cover Graphic: Extent of ET production for southeast Idaho (Landsat path 40) showing higher growing season evapotranspiration as bright green.

Table of Contents

Table of Contents, continued

List of Tables

List of Figures

List of Figures, continued

List of Figures, continued

1. Introduction

This report provides a description of the procedures and products used during processing of satellite, weather and land-use data for the southeastern and southcentral portions of Idaho to produce spatial maps of monthly evapotranspiration (ET) for the Eastern Snake Plain Aquifer (ESPA) region and surrounding areas in near real time for provisional and final monthly and seasonal products . The provisional and final products represent estimated evapotranspiration information presented at 30 m resolution in the form of ET (mm per month) and also presented as a fraction of reference evapotranspiration (ET_rF) based on the alfalfa reference crop. The Landsat scenes lie along the USGS World Reference System-2 (WRS-2) paths 40 and 39 and cover WRS-2 rows 29 and 30. In addition, a portion of WRS-2 row 31 was included for both paths to complete the production of data for all areas north of the southern Idaho state line. Rows along each path were combined into a single mosaic for the path prior to processing.

For this application, provisional ET and ETrF products were generated in near real time during 2016. When a useful Landsat image was available, it was processed in "near-real-time", generally within 3 to 4 days of adquisition time. As 2016 progressed, provisional monthly ET and ETrF images were produced and were made available to IDWR within the first week of the following month. The provisional monthly ET, ET_rF and ET maps were considered to be provisional products because they were developed using a limited amount of satellite images, gross cloud masking, without filling of clouded portions of images, using forecasted ET_rF information, and using linear interpolation as part of the time integration process. Usually, a monthly ET image requires the use of satellite images corresponding not only to the month itself; but also to prior and subsequent months to best describe the evolution of ET caused by the development of agricultural crops. For example calculation of ET for the month of May needs at least one clear image during April and during June for best estimates.

The final monthly and seasonal ET and ET_rF products that were processed after the end of the 2016 growing season are based on a complete set of images for the season that have been sharpened (L8), accurately cloud filled and reviewed for spatially appropriate ET_rF values by personal not involved in the calibration process. In the final image review, some images were discarded because they were judged to be too cloudy to provide for accurate cloud filling. During the interpolation process, a cubic spline is used to interpolate between image dates using a customized dampening function to closely follow expected vegetation growth and ET behavior. The resulting monthly products for the two paths are also compared with each other in the path overlap area. If substantial differences in ET are noted for the overlap area, the monthly images are adjusted. This adjustment procedure can involve adjusting the monthly product for both paths or for only one path. Usually differences in ET between paths occur because of differences in background evaporation from soil that is caused by differences in image dates for the two images and their proximities to antecedent precipitation events. Adjustment usually focuses on adjustment to ET for low vegetation pixels.

ET was produced using the METRIC model developed by the University of Idaho (Allen et al. 2007a,b; 2011). The METRIC procedure utilizes visible, near-infrared and thermal infrared energy spectrum bands from Landsat satellite images and weather data to calculate ET on a 30 m pixel by pixel basis. ET is estimated from a surface energy balance, where net radiation at the surface (R_n), comprised of both both solar and thermal radiation, is partitioned into ground heat flux (G) and sensible heat flux (H) and ET. The impact of topography of the region on the surface energy balance is incorporated into METRIC via a digital elevation model (DEM), and is used to account for impacts of slope and aspect on solar radiation absorption and impacts of elevation on surface temperature. The surface energy balance in METRIC was uniquely calibrated for each image date using ground based meteorological information and identified 'anchor' or 'endpoint' conditions (the cold and hot pixels of METRIC) present in each image. A detailed description of METRIC can be found in Allen et al. (2007a,b; 2011).

Figure 1 shows the domain of the Landsat images processed by METRIC for year 2016. The figure shows a 'false composite' of bands 2, 3 and 4 (Landsat 7) and 3,4,5 (Landsat 8), where 'green vegetation' displays as a red color. Forest vegetation in mountainous areas show as a dark red color and broadleaf vegetation, including agricultural crops, generally show as a light red color.

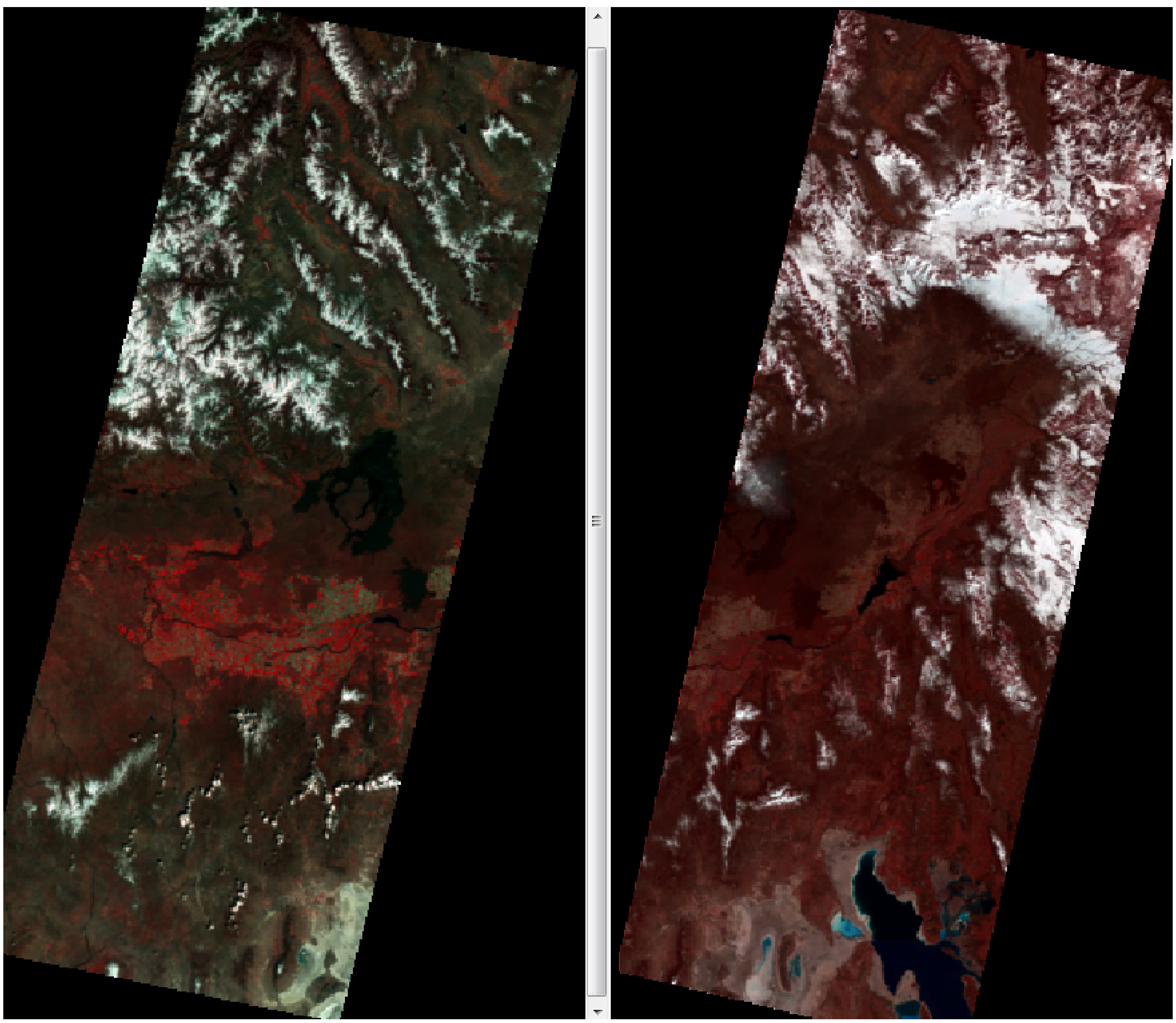


Figure 1. Left: False color composite of path 40 Landsat 7 image, rows 29, 30 and the upper portion of 31, for 04/20/2016. Right: Landsat 8 path 39, rows 29, 30 and 31, for 03/20/2016.

2. Image Selection and pre-processing

Imagery from Landsat satellites is utilized in METRIC due to the relatively high resolution of 30 m and the presence of a thermal band. The 30 m resolution provides ET information at the sub-field scale, which is important for agricultural water management and for water rights management. The thermal information permits application of a surface energy balance that is able to determine ET under both well-watered and stressed conditions. For 2016, images from both Landsat 8 and Landsat 7 satellites were processed. Landsat 7 was launched in 1999. Landsat 8 was launched in February 2013.

Landsat 7 images acquired after May 2003 are less preferred than from Landsats 5 and 8. This is due to an anomaly with the Landsat 7 satellite caused by the malfunction of the scan line corrector (SLC-off) beginning in May 2003. As a consequence, Landsat 7 images processed for year 2016 are “SLC-off” images that contain wedge shaped gaps extending from the edges of the image and stretching towards the centers, as shown later in Figure 4. The gaps in ET_rF maps produced by METRIC from Landsat 7 were filled in during post processing as a standard part of METRIC processing using the natural neighbor tool of Arc-GIS.

An important criterion for image selection is an assessment of cloud conditions at the time of the satellite overpass. The clearness of the atmosphere is impacted by clouds, including thin cirrus clouds, and jet contrails, smoke and haze. The occurrence of these conditions over an area of interest can render that part of the image unusable for processing in METRIC. Even very thin cirrus clouds can indicate lower surface temperature than the actual ground surface. Because METRIC uses surface temperature estimates to solve the energy balance, areas having cloud cover create error in the ET estimates. In addition, areas recently shaded by moving clouds may appear to be cooler than other sunlit areas because they have not yet reached a thermal equilibrium corresponding to the clear sky energy loading. These areas adjacent to clouds and shadows are generally also masked out of the processed images and replaced with information from other image dates, as described later. Initial cloud assessment was done by viewing Landsat preview images at http://glovis.usgs.gov/ and noting the amount of cloud cover in the image, especially over irrigated regions in the scene. Special preference was given for clearness over irrigated areas of the study area.

Landsat images were downloaded from the USGS website at: http://glovis.usgs.gov/ . A total of 17 Landsat image dates were selected for METRIC processing for path 40, and 13 Landsat images were processed for path 39 according to clearness of the images over irrigated areas and the date of the image relative to other images to produce the provisional monthly products for April through October 2016. These dates are listed in Table 1.

A total of 30 Landsat dates were processed for the two paths over the March-October 2016 period to develop the provisional monthly and seasonal ET and ET_rF products. For the final monthly and seasonal ET and ET_rF products, 29 Landsat image dates were processed (Table 1). The June 7th images for Path 40 were judged to be too cloudy to fill, with filling results too uncertain to be useful.

Table 1. Dates of the Landsat 8 and 7 satellite images used for METRIC processing in 2016.

#	Path 40	Image Type	Path 39	Image Type
1	03/19/2016	L7 ETM+	03/20/2016	L8 OLI-TIRS
2	04/12/2016	L8 OLI-TIRS	04/05/2016	L8 OLI-TIRS
3	04/20/2016	L7 ETM+	04/21/2016	L8 OLI-TIRS
4	05/30/2016	L8 OLI-TIRS	05/31/2016	L7 ETM+
5	06/07/2016	L7 ETM+ **	06/08/2016	L8 OLI-TIRS
6	06/23/2016	L7 ETM+	06/24/2016	L8 OLI-TIRS
7	07/01/2016	L8 OLI-TIRS	07/02/2016	L7 ETM+
8	07/09/2016	L7 ETM+	07/18/2016	L7 ETM+
9	07/17/2016	L8 OLI-TIRS	07/26/2016	L8 OLI-TIRS
10	07/25/2016	L7 ETM+	08/03/2016	L7 ETM+
11	08/02/2016	L8 OLI-TIRS	08/19/2006	L7 ETM+
12	08/10/2016	L7 ETM+	09/20/2016	L7 ETM+
13	08/18/2016	L8 OLI-TIRS	09/28/2016	L8 OLI-TIRS
14	09/11/2016	L7 ETM+		
15	09/19/2016	L8 OLI-TIRS		
16	09/27/2016	L7 ETM+		
17	10/21/2016	L8 OLI-TIRS		
*** Image considered to be too cloudy to fill for final product.*				

There were no viable Landsat and VIIRS (Visible-Infrared Imaging Radiometer Suite) images for the month of October for Path 39. Landsat (7 and 8) images were considered to be too cloudy for processing.

DEM and Land Use maps used for METRIC processing

Other basic input files needed during METRIC processing, besides the satellite images, include a Digital Elevation Model (DEM) and Land Use (LU) images. The DEM is used during METRIC processing to adjust surface temperatures for lapse effects caused by elevation variation. In addition, maps of slope and aspect (aspect is the cardinal direction of an inclined surface) are derived from the DEM at 30 m resolution and are used to estimate solar radiation on slopes and in defining aerodynamics of heat convection in mountains. The slope and aspect images were created using the tools of the ERDAS Imagine processing system based on the DEM. ERDAS IMAGINE is a image processing application produced by ERDAS for geospatial applications, particularly from satellite. The version used in this study was the 2013 version 13.0.2. ERDAS IMAGINE is aimed primarily at geospatial raster data processing. ERDAS contains a ModelMaker toolbox that provides for scripting of the image processing procedure. This procedure was used to develop the METRIC code.

A land use (LU) map was used to support the estimation of aerodynamic roughness and soil heat flux during METRIC processing. The NLCD (National Land Cover Database, 2011) Land Use map and the DEM (30 m resolution) data sets were obtained from the USGS-seamless webpage (http://seamless.usgs.gov/).

3. The METRIC Model

METRIC™ (Mapping Evapotranspiration with high Resolution and Internalized Calibration) is an ERDAS coded model that bases the ET estimate on the evaluation of the energy balance at the earth's surface. METRIC™ processes instantaneous remotely-sensed digital and weather data and estimates the partitioning of energy into net incoming radiation (R_n), heat flux into the ground (G), sensible heat flux to the air (H), and latent heat flux (LE). The latent heat flux is computed as a residual in the energy balance, represents the energy consumed by ET:

$$LE = R_n - G - H \tag{1}$$

where LE=latent energy consumed by ET; R_n=net radiation; G=sensible heat flux conducted into the ground; and H=sensible heat flux convected to the air. The main advantage of using energy balance is that actual ET is computed, rather than a potential ET that is based on amount of vegetation, so that reductions in ET caused by shortage of soil moisture are captured. A disadvantage of the energy balance approach is in the complexity of calculations and the need for human oversight during calibration. In traditional applications of energy balance, the computation of LE is only as accurate as the summed estimates for R_n, G, and H. METRIC employs a calibration strategy to overcome this disadvantage by focusing the internal calibration on LE, with H used to assimulate intermediate estimation errors and biases.

METRIC™ utilizes spectral raster images from the visible, near infrared, and thermal infrared energy spectrum to compute the energy balance on a pixel-by-pixel basis. In METRIC, R_n is computed from the satellite-measured narrow-band reflectance and radiometric surface temperature; G is estimated from R_n, radiometric surface temperature, sensible heat flux and vegetation indices; and H is estimated from surface temperature ranges, surface roughness, and wind speed using buoyancy corrections. Figure 2 shows a general schematic of the METRIC process.

METRIC is calibrated uniquely for each image date due to the unique surface temperature conditions occurring on each image date and changing weather conditions including wind speed and air humidity. The main objective of calibration is the production of accurate estimates of ET from lands having agricultural production. This is done because of the generally high importance of ET from agricultural areas. Calibration settings focus on agricultural areas because of their more uniform and predictable behavior which improves the accuracy of the calibration of the sensible heat flux function of METRIC. The calibration of METRIC automatically transfers to other land use types in an image, including forest and rangeland.

METRIC version 3.0 was used for the UI processing, The 3.0 version was produced by the University of Idaho in 2013-16. A detailed description of METRIC can be found in Allen et al. (2007a,b; 2008).

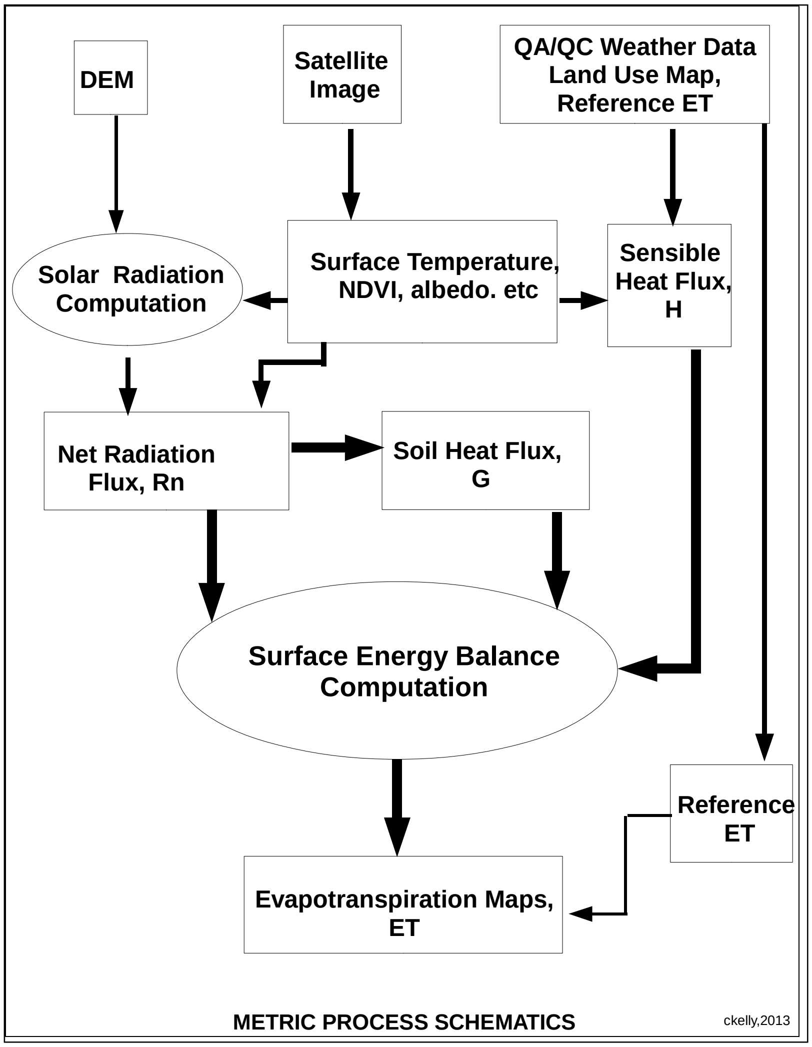


Figure 2. General schematic of the METRIC process.

4. Weather data processing

METRIC utilizes alfalfa reference ET (i.e., ET_r) as calculated by the ASCE standardized Penman-Monteith equation (ASCE-EWRI 2005) for calibration of the energy balance process and to establish a daily soil water balance to estimate residual soil evaporation from bare soil following precipitation events (Allen et al. 2007a). Reference ET represents a near maximum rate of ET from full vegetation cover that is not short of soil water. The rate of reference ET is largely limited by the amount of energy available from the sun and surrounding air to convert liquid water to vapor. The ET_r is used as a means to 'anchor' the surface energy balance by representing the ET from locations having high levels of vegetation and cooler radiometric surface temperatures. High quality estimates of ET_r are needed, which, in turn, require high quality weather data. Therefore, before processing the satellite images, the quality and accuracy of the meteorological data were assessed. For near real time processing only a preliminary assessment is performed because time series trends are not available for the entire year.

Hourly weather for calibration

Hourly weather data time steps are needed to represent ET_r at the time of the Landsat overpass for calibration of the METRIC energy balance estimation process. ET_r was calculated using the RefET software (version 3) of the University of Idaho (Allen, 2011). RefET is a Visual Basic program distributed freely by the University of Idaho. It is designed to read weather data for hourly or daily timesteps and calculate reference ET using a number of selected methods. RefET includes the ASCE standardized Penman-Monteith equation and accurately produces standardized reference ET estimates for both alfalfa and grass reference surfaces.

Hourly data from weather stations in each path were evaluated for use with paths 39 and 40. The stations selected (Aberdeen in path 39 and Twin Falls-Kimberly in path 40) are operated by the Pacific Northwest Cooperative Agricultural Network (AGRIMET) of the US Bureau of Reclamation. The coordinates and characteristics of the meteorological stations are presented in Table 2.

Table 2. Characteristics of the weather stations used for calibration of METRIC in 2016.

Station	Latitude	Longitude	Elevation (m)	Institution in charge		Path
Aberdeen	42° 57' 12"	112° 49' 36"	1341	AGRIMET		39
Twin Falls-Kimberly	42° 32' 46"	114° 20' 43"	1195	AGRIMET		40

Sources: https://www.usbr.gov/pn/agrimet/location.html

Daily weather data for ET_r surfaces.

Daily ET_r surfaces are required in the METRIC process to develop daily ET from the interpolated ET_rF images, that is then used to compute montly and seasonal ET. The daily ET_r surfaces are interpolated using point reference ET calculated using meteorological data downloaded from automatic weather stations. The ET_r for each automated weather station was calculated using the ASCE standardized Penman-Monteith equation with coefficients for alfalfa reference ET.

The near real time daily ET_r surfaces for the area are based on meteorological data obtained from 66 automatic weather stations in and surrounding the area described in Appendix A. The meteorological data sets were not quality controlled for the provisional METRIC products that were produced in near-real-time. The final daily ET_r surfaces were based on quality reviewed and adjusted meteorological data from 60 AWS stations. The daily surface estimates of ET_r were generated from automated weather stations lying in Idaho, Neveda, Utah, Wyoming and Montana using a natural neighbor and a spline methods available in ArcGIS at a 3km resolution.

Using a daily soil water balance model for METRIC calibration.

An hourly and daily soil water balance was applied to the 2016 period using precipitation and ET_r data from the Twin Falls Agrimet weather station for path 40 and for the Aberdeen Agrimet station for path 39. The water balance estimates daily residual evaporation from a bare soil surface as shown in Figures 3a and 3b. The soil water balance is based on the two-stage daily soil evaporation model of the United Nations Food and Agriculture Organization's Irrigation and Drainage Paper 56 (Allen et al 1998). The procedure employs the skin evaporation enhancement of Allen (2011) that increases the magnitude of evaporation spikes following light precipitation events. Figure 3a shows a simulation of evaporation from the upper 0.15 m of soil at Twin Falls. The residual evaporation is used during assignment of a value to the hot pixel condition for each image date. Figure 3b shows a simulation of evaporation from the upper 0.15 m of soil at Aberdeen. The precipitation and wet soil conditions for path 39 during the month of October are shown in Figure 3b.

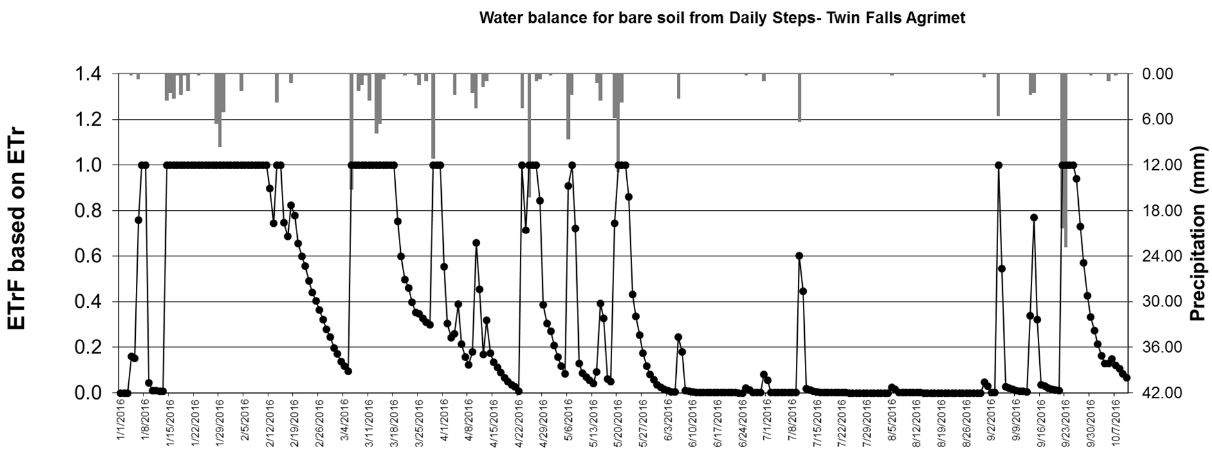


Figure 3a. Daily ET_rF for bare soil estimated from the soil water balance for 2016 using weather data from the Twin Falls Agrimet weather station.

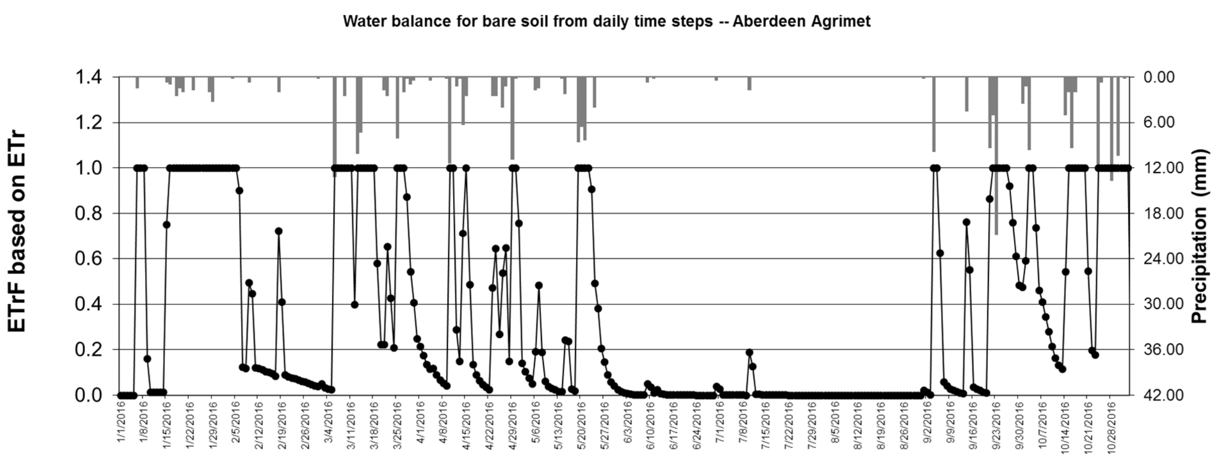


Figure 3b. Daily ET_rF for bare soil estimated from the soil water balance for 2016 using weather data from the Aberdeen Agrimet weather station.

The daily soil water balance is included in the METRIC calibration spreadsheet as an essential and routine calculation used during image calibration. Usually a one year-long set of daily ET_r and precipitation data are input to the sheet. The general soil type for the top 0.10 to 0.15 m of soil is indicated along with field capacity and wilting point values and an estimate of the readily evaporable water (REW). The REW value is provided in a table in the METRIC manual for a variety of soil textures. Standard coefficients for skin layer retention efficiency suggested by Allen (2011) were used.

The FAO-56 evaporation model typically reduces the ET_rF value, also termed K_e, for bare soil to zero after five to ten days of drying, depending on the time of year and soil characteristics. However, in reality, a typical bare agricultural soil can be expected to continue to evaporate at a small rate beyond the first several weeks of drying due to diffusion of liquid water and vapor from beneath the upper soil layer (Allen 2011). This evaporation can continue at very low rates for several additional weeks, provided no new wetting events occur, especially from tilled soils that have a moderate amount of water stored within the soil profile. This is typical of agricultural soils. Therefore, the ET_rF for the hot pixel is often set to 0.10 when the hot pixel is selected from an agricultural area where stored water is likely to be available from the subsoil (below 0.15 m). When periods of about 30 days or longer have occurred since precipitation events and likely since an irrigation event, then the ET_rF for the hot pixel may be set to 0.0.

5. METRIC™ Image Processing

METRIC produces 30x30 m spatial resolution maps of instantaneous ET_rF (Fraction of Reference Evapotranspiration) and actual ET at satellite overpass time for every image date. . Those instantenous images are integrated to produce daily ET and ET_rF assuming a constant ET_rF value over the course of the image day for agricultural areas, and assuming a constant evaporative fraction for non-advective natural areas as explained in the METRIC manual. After calibration and review of the calibration, the daily ET_rF images are cloud masked and gapfilled. For the final products, the cloud masks are further refined for each image. The sharpening and cloud filling processes were only performed on the images used for the final product. Appendix C has the final calibrated and cloud masked images used for the final products.

Image Calibration

METRIC uses a vertical near surface-to-air temperature difference, dT, to estimate sensible heat flux. Sensible heat flux (H) is the amount of heat that is convected from a surface into the air, thereby reducing the amount of available energy for evaporation. The dT function is modeled as a linear function of surface temperature. It is defined using the properties of two user selected anchor pixels. These anchor pixels are the “cold” and the “hot” pixels. The cold and hot pixels represent the extreme conditions encountered within the image. The cold pixel represents a condition having nearly complete conversion of available energy into evapotranspiration. The hot pixel represents a condition having nearly zero conversion of available energy into evapotranspiration. The cold anchor pixel generally represents a fully vegetated and actively transpiring vegetation. The hot anchor pixel represents a bare and dry or nearly dry agricultural soil with little or no vegetation. The selection of cold and hot anchor pixels by the user is described by Allen et al., (2007b, 2008, 2014). In most applications, cold and hot pixels are selected from agricultural fields for consistency and to match assumptions made in the estimation of soil heat flux, where the soil heat flux function in METRIC was developed using field data from agricultural soils. The radiometric surface temperature used to estimate dT is adjusted for elevation to account for differences in radiometric surface temperature occurring as a result of elevation differences.

The individual Landsat images (path/row) were not calibrated individually but as a mosaiced path (path 39 rows 29-31 and path 40 rows 29-31) for each image date. For the provisional process the calibration was reviewed by the adjoining path personnel and calibration adjusted as needed. The final products are based on images further reviewed by personnel not involved with the initial calibration and review. Table 3 has the final ET_rF values after final calibration for the associated hot and cold pixels for paths 39 and 40.

Table 3. ET_rF values assigned to the hot and cold pixels for each image for path 39 and 40 and their locations (X, Y IDTM coordinates in meters). NDVI and ETrF are dimensionless.

Path 39						Path 40					
Date		X	Y	NDVI	ET_rF	Date		X	Y	NDVI	ET_rF
3/20	Cold	2589501	1295330	0.735	1.00	3/19	Cold	2481630	1248330	0.622	0.87
	Hot	2632350	1337700	0.139	0.35		Hot	2516310	1251630	0.147	0.53
4/5	Cold	2590350	1313190	0.676	0.85	4/12	Cold	2452920	1273770	0.873	1.05
	Hot	2591190	1312230	0.138	0.14		Hot	2532540	1265310	0.143	0.17
4/21	Cold	2593350	1306020	0.855	1.05	4/20	Cold	2483968	1250701	0.845	1.05
	Hot	2590800	1313550	0.143	0.10		Hot	2483880	1252980	0.138	0.05
5/31	Cold	2611800	1305180	0.866	1.05	5/30	Cold	2445990	1259850	0.811	1.05
	Hot	2575680	1297620	0.153	0.10		Hot	2466000	1258320	0.138	0.06
6/8	Cold	2583720	1291050	0.825	1.05	6/23	Cold	2464470	1272750	0.859	1.05
	Hot	2512470	1255470	0.152	0.05		Hot	2447731	1269055	0.152	0.05
6/24	Cold	2584980	1290510	0.854	1.05	7/1	Cold	2448600	1268280	0.816	1.05
	Hot	2575680	1297620	0.157	0.05		Hot	2507338	1247311	0.139	0.05
7/2	Cold	2616990	1333620	0.867	1.05	7/9	Cold	2478659	1252200	0.841	1.05
	Hot	2577360	1286820	0.145	0.05		Hot	2453039	1265908	0.112	0.05
7/18	Cold	2620140	1330110	0.856	1.05	7/17	Cold	2478545	1252208	0.848	1.05
	Hot	2574870	1297320	0.153	0.05		Hot	2459271	1264526	0.145	0.05
7/26	Cold	2587290	1295850	0.843	1.05	7/25	Cold	2473862	1251690	0.837	1.05
	Hot	2520750	1284659	0.157	0.05		Hot	2493471	1244001	0.158	0.05
8/3	Cold	2599230	1292880	0.860	1.05	8/2	Cold	2448120	1277010	0.830	1.05
	Hot	2621250	1407600	0.143	0.05		Hot	2482219	1245983	0.164	0.05
8/19	Cold	2586900	1312860	0.831	1.05	8/10	Cold	2448240	1277069	0.825	1.05
	Hot	2577390	1286310	0.130	0.05		Hot	2472362	1255018	0.143	0.05
9/20	Cold	2600670	1311030	0.843	1.05	8/18	Cold	2533023	1290930	0.751	1.05
	Hot	2593507	1308272	0.141	0.47		Hot	2423696	1295609	0.131	0.05
9/28	Cold	2597730	1313760	0.855	1.05	9/11	Cold	2473739	1274129	0.831	1.05
	Hot	2630370	1318980	0.163	0.39		Hot	2498790	1240230	0.139	0.05
						9/19	Cold	2469711	1275094	0.822	1.05
							Hot	2480130	1259550	0.153	0.05
						9/27	Cold	2453317	1264768	0.823	1.05
							Hot	2440413	1275624	0.143	0.17
						10/21	Cold	2463209	1274669	0.814	1.05
							Hot	2399400	1302300	0.148	0.22

Gapfilling for Landsat 7 images

Landsat 7 images acquired after May 2003 have information gaps caused by the malfunction of the scan line corrector (SLC). As a result, Landsat 7 images processed for March-November 2016 were "SLC-off" images where wedge shaped gaps exist in the images, extending from the edges of the image and stretching towards the centers. Full description of the SLC-off malfunction is provided at USGS web sites (http://landsat.usgs.gov/products_slcoffbackground.php). To obtain as complete coverage as possible, the gaps in ET_rF maps produced by METRIC were filled in during post processing using the natural neighbor tool of ArcGIS. This tool 'grows' pixels into the SLC-off gaps based on information from surrounding pixels. The process is similar to the growth of ice crystals. Our experience has been that the natural neighbor tool provides the best end results as compared to other approaches. Other approaches include the use of surrogate neighboring pixels to fill all bands, for example, by Chen et al. (2011). However, that technique is not tested for the thermal band. Figure 4 shows a close-up of an area near Murtaugh, Idaho where the natural neighbor interpolation procedure was applied. The quality of the interpolation depends on the location and size of the gap, being better over homogenous landscapes.

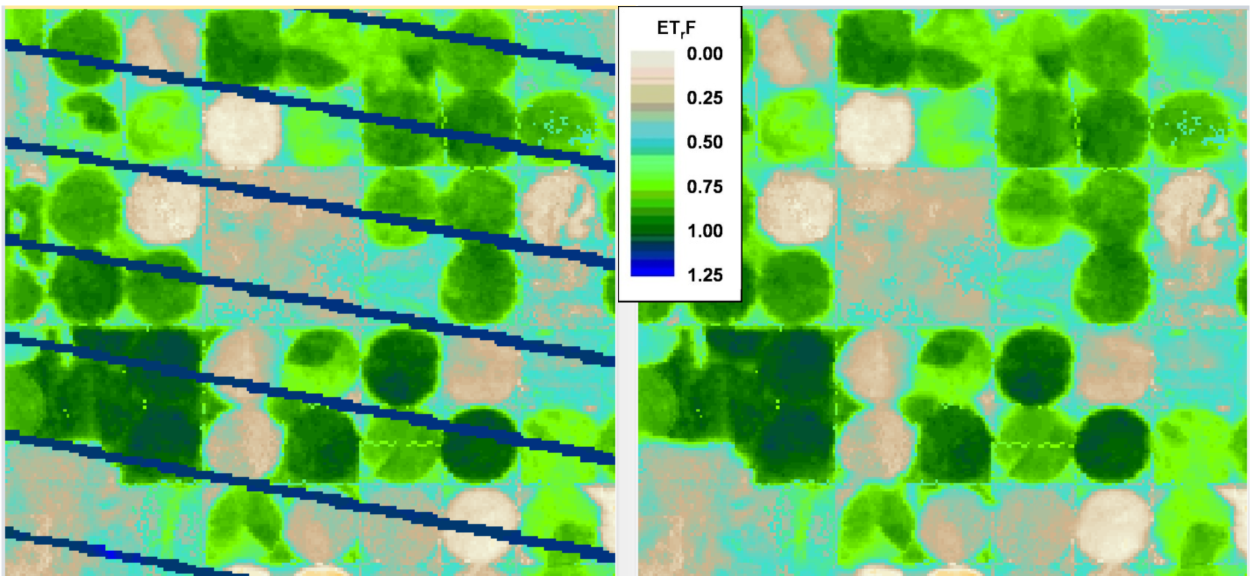


Figure 4. Left: Close-up of ET_rF image for 04/20/2016, showing gaps (stripes) originated from the Landsat 7 image. Right: The same ET_rF map, after gaps were filled using natural neighbor interpolation.

Sharpening of Landsat 8 Images

Landsat 8 images have 100 m spatial resolution for the longwave (thermal) band, which is approximately 3 times coarser than the 30 m for coincident shortwave bands. In METRIC, thermal information tends to dominate the production of ET and therefore the resolution of the final ET product. To improve the spatial quality of results, a procedure known as thermal sharpening was applied to the thermal band, using 30 m NDVI as an input, to transform the thermal images to a 30 m equivalent. This sharpening of thermal data improves the spatial accuracy and discreetness of the final individual ET_rF images generated with the METRIC code. This procedure is described in the METRIC manual (Allen et al., 2014) and in a paper by Trezza et al. (2008).

The basic sharpening procedure is based on the application of an established Ts (radiometric surface temperature) vs NDVI relationship to produce a first estimate of Ts at every 30 m short wave pixel, assuming a linear relationship and correspondence between NDVI and Ts that is defined by the Ts and NDVI settings for the hot and cold pixels. Later, to preserve original Ts information, this first estimate of Ts is adjusted so that Ts averaged over all shortwave pixels lying within an original thermal pixel matches the original average surface temperature Ts of that thermal pixel. In most of the cases the redistribution of the bias between the original thermal Ts and the estimate Ts is an iterative process, with most adjustment distributed to low-NDVI pixels that may be more likely to have residual wetness and therefore cooler temperature.

A multiple run technique is used in sharpening Ts from the current level 1, terrain-corrected (L1T) images of EROS since the original thermal pixel locations are no longer known, due to the use of cubic convolution (CC) resampling by EROS that is performed on the thermal band during the creation of 30 m L1T products. The thermal sharpening procedure was applied to Landsat 8 images where the original thermal pixel size is 100 m. Sharpening was not applied to Landsat 7 imagery since the original thermal pixel size is already 60 m. Therefore, only 4 degrees of freedom remain for distributing temperature among the four 30 m pixels in a 60 m pixel. This constraint creates limitations on accuracy and, again, sharpening is not generally needed for 60 m thermal pixels to produce ET images having high spatial definition. The sharpening procedure is performed in ArcGIS using a Python-script developed by the University of Idaho. Figure 5 shows an example of an ET_rF map, before and after sharpening surface temperature.

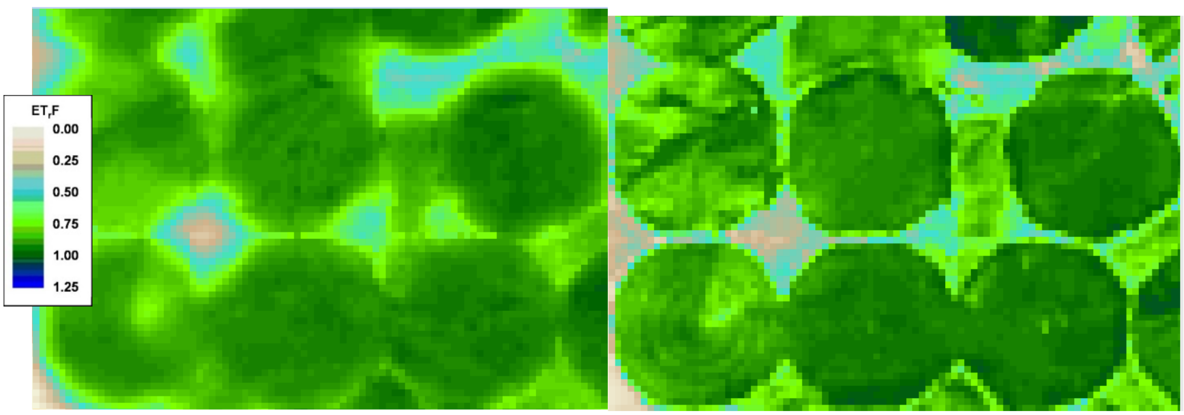


Figure 5. Left: Close-up of ET_rF image from path 40 prior to using sharpened surface temperature; the area is south of the Snake River (Twin Falls county). Right: The same ET_rF map after sharpening the original surface temperature.

Cloud Filling of Cloudy Images

Satellite images often have clouds in portions of the images, and the paths 40 and 39 images for 2016 were no exception. ET_rF cannot be directly estimated for clouded areas using surface energy balance because cloud temperature masks surface temperature and cloud albedo masks surface albedo. ET_rF for clouded areas should be filled in prior to splining of monthly ET, because clouded (or 'missing') portions of an image generally result in long periods between valid ET_rF data (sometimes longer than several months).

Clouds and shadows were manually identified and outlined by creating line polygons in ERDAS Imagine in the form of an AOI image that overlaid the original image. The outlines included both clouds and shadows and were drawn to be about 200 to 500 m larger than the clouds and shadows. This was done to insure that areas near clouds where extent of cloudiness was uncertain were masked out, including areas near clouds that were in direct sunlight at the time of the satellite overpass, but may have been shaded a few minutes earlier and therefore may have been colder than temperatures associated with the surface energy balance, and therefore would give inaccurate estimates of ET.

ET_rF of cloudy areas associated with an image were not used in the linear interpolation of the provisional daily ET_rF but were instead replaced by ET_rF values interpolated from before and after images when the area is cloud free. For example if an area was cloudy on April 12, the ET_rF for the area is based on linear interpolation between March 19th and April 20th provided the area was cloud free for those image dates.

For the final products the cloud masked areas were filled using the procedure outlined in the Appendix 19 of the METRIC Manual Version 3. The gaps in the ET_rF maps occurring as a result of the cloud masking are filled in using linear time-weighted interpolation of ET_rF values from the previous image and the nearest following satellite image date having a valid ET_rF estimate, adjusted for vegetation development. The Normalized Difference Vegetation Index (NDVI) is used to indicate change in vegetation amount.

During the ET_rF filling of cloud masked areas, the interpolated values for the areas having mostly bare soil are adjusted for differences in residual soil moisture between the image dates occurring as a result of heterogeneities in precipitation (such as by local summer showers) based on cold and hot pixel NDVI and ET_rF values for the previous and following satellite image dates. This procedure is needed to remove artifacts of this precipitation-derived evapotranspiration that are unique to specific image dates but that may not be representative of the image date that is to be represented by the ET_rF from the previous and the following images.

October Image for Path 39

As seen in Table 1, there was not a usable Landsat image for Path 39 during the months of October and November 2016. Therefore, the October monthly ET_rF image was produced using spline interpolation using images from previous months and using synthetic images created for the month of November. After the Path 39 October ET_rF image was generated, the image was adjusted by comparing against Path 40 October ET_rF results, that were assumed to be more representative due to the availability of imagery in Path 40 for the month of October. The adjustment to Path 39 ET_rF considered the following:

a) Path 39 agricultural pixels in the overlapped area with Path 40 were replaced by corresponding pixels located in Path 40.

b) ET_rF in desert areas (NLCD classes 71 and 52), Basalt (Class 31), and Water (Class 11) were adjusted to match Path 40 results.

6. Interpolation of METRIC Images to Summary Products

The interpolation of individual METRIC ET_rF images to monthly and multi-month summary products requires "cloud free" beginning and ending images for dates that bracket the interpolation period. These beginning and ending images are used with the processed METRIC images to develop daily ET_rF images by interpolation. For the provisional products a linear interpolation was used. The final products were based on a spline with dampening interpolation procedure. The daily alfalfa-based reference ET maps (ET_r) (Appendix A) were multiplied by the interpolated daily ET_rF surface to determine daily ET ($ET= ET_rF * ET_r$). The daily ET and ET_r were summed to determine period totals. The ratio of total ET to total ET_r is the ET_rF for the period.

Beginning ET_rF Synthetic Image

The interpolation of daily ET_rF (fraction of reference ET) images relies on an initial ET_rF image absent of missing ET_rF data for all pixels. For 2016, due to cloudy conditions for much of the March Landsat images, the initial image is a synthetic image derived from meteorological data, computed reference evapotranspiration, and land surface conditions for dormant vegetation. The procedure used to create the synthetic image is discussed in Appendix B. For the provisional products the synthetic was based on meteorological data that was not reviewed or quality assessed. The synthetic image used for the final product was based reviewed and adjusted meteorological data. Both images were developed to represent the ET_rF on March 1, 2016 for the study area. Figure 6 shows the provisional and final synthetic images for March 1st 2016.

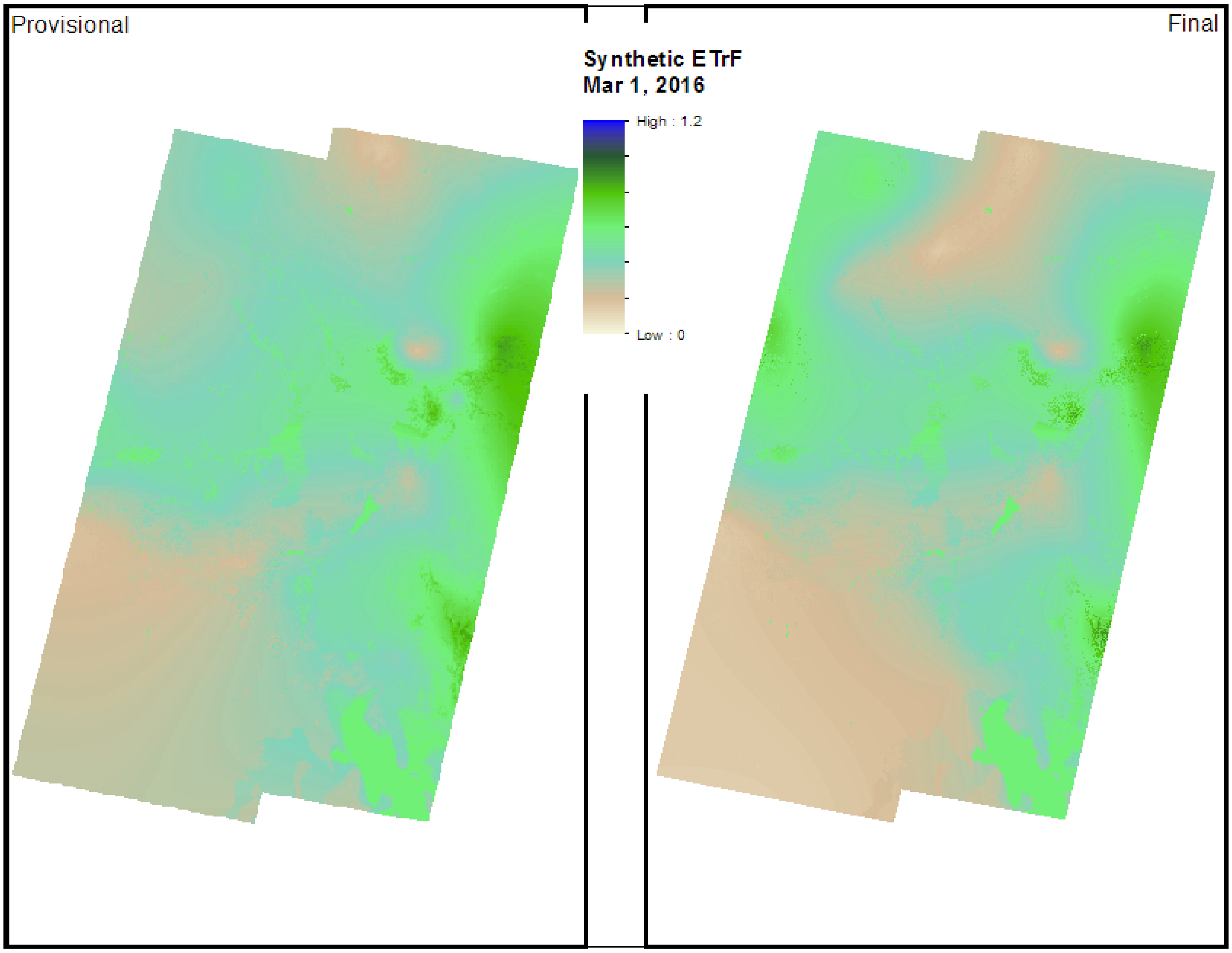


Figure 6. Synthetic ET_rF images: provisional (left) and final (right) representing March 1, 2016.

Ending ET_rF Images

The daily interpolation of ET_rF between METRIC images and development of daily ET from ET_rF and daily ET_r to compute monthly ET and ET_rF requires an ET_rF surface extending, in time, beyond the month or period in consideration. The current interpolation script methods require extrapolated images to be complete without missing ET_rF values caused by clouds or Landsat 7 SLC gaps.

Near Real Time (Provisional) Products

For near real time METRIC products the extrapolated estimated ET_rF surface was derived from known previous ET_rF images by linear forecasts. The last two images having clear pixels for any location where used to linearly project the ET_rF for the pixel to the 1^{st} of the month. The extrapolated image ET_rF values from the linear forecast were limited to the range 0.1 and 1.0 to keep the extrapolation from exceeding expected bounds. The bounding range was changed from the April submission to 0.05 and 1.0. In the overlap area between the two Landsat paths (Path 39 and Path 40) the average of the two extrapolated ET_rF values were used. This reduced monthly ET and monthly ET_rF differences between individual fields lying in the overlap area between the path products.

Final Products

For the final processing, two ET_rF images were produced to represent November 6^{th} and 7^{th} conditions to serve as growing season endpoints for the splining and time integration of ET. The two dates were dates having Landsat imagery. The path 39 image (November 7^{th}) was relatively clear but with the presence of extended, thin and irregularly-distributed clouds that tended to influence the surface temperature estimates and therefore estimates for ET_rF. In addition, soil moisture conditions for the November 6^{th} and 7^{th} period were wet due to more than 35 mm of precipitation during the last week of October. The cloudy conditions and more or less uniformly wet image that lacked substantial surface temperature variation prevented applying the temperature-based METRIC procedure to the image. Consequently, a November 7^{th} synthetic ET_rF image was developed using NDVI from the image, which was less impacted by the thin clouds. The ET estimates from NDVI represent transpiration associated with well-watered vegetation. Those estimates were combined with the K_e (soil evaporation coefficient) in reverse proportion to NDVI to produce ET estimates that had both E and T components. The Path 40 Landsat image for November 6^{th} was 85 to 90% cloud covered and like path 39 had soil moisture conditions and associated surface temperature anomolies that prevented using the METRIC process for determining ET_rF. A NDVI and K_e based ET_rF image was developed, similar to path 39, where NDVI for cloudy areas was estimated based on earlier images and the change in NDVI over time according to NLCD land classes.

Daily Alfalfa Reference Evapotranspiration (ET_r)

Daily reference evapotranspiration (ET_r) was computed based on daily meteorological data as discussed in an earlier section and Appendix A. The daily ET_r values for the various sites were interpolated for the path 39 and 40 area using a weighted average of a spline and natural neighbor methods included in ArcGIS. The spline surface weight was one-third with values limited to range between 50% of the minimum ET_r and 150% of the maximum ET_r for the stations. The natural neighbor interpolation weighting was two-thirds. For provisional products, the daily surfaces were based on non reviewed meteorological data for all 66 stations. For the final products the daily surfaces were based on reviewed and adjusted meteorological data for 60 stations. Figure 7 shows the seasonal sum of the daily ET_r surfaces based on provision and final processing.

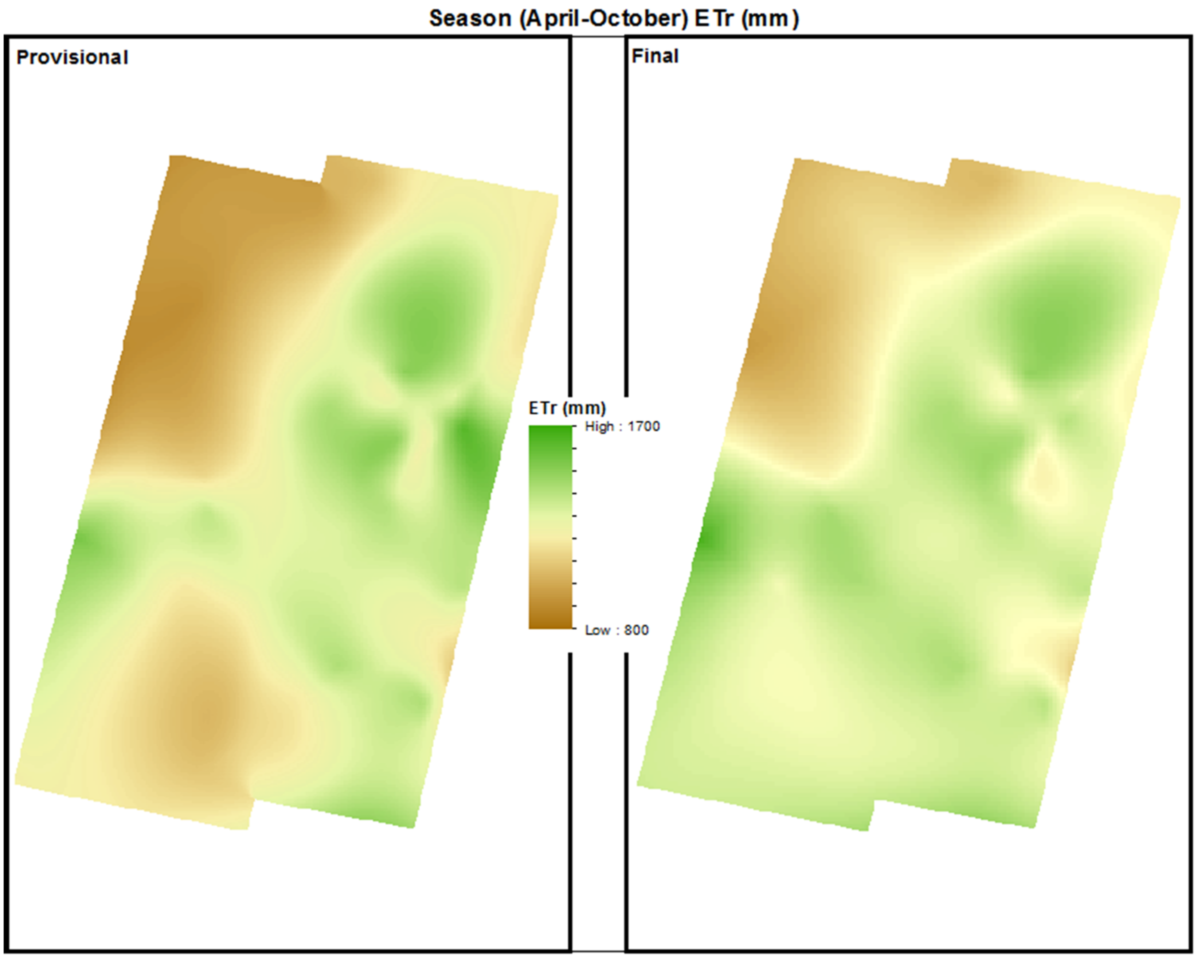


Figure 7. Seasonal (April through October, 2016) ET_r images: provisional (left) and final (right)

Monthly and seasonal (Apr-Oct) final ET/ET_rF/ET_r images

For each path, the final products consist of several image sets: monthly and seasonal (Apr-Oct) ET information. Cloud metadata information was only generated for the provisional products. Each monthly and the seasonal ET images have three layers. The first layer is the monthly or seasonal ET in mm, the second layer is the monthly or seasonal ET_rF, and the last layer is the monthly or seasonal ET_r in mm. These images have file names starting with ET and ending with the month or period. For example "*ET_P39_2016_Jun*" contains the ET, ET_rF and ET_r for path 39 during June 2016. Likewise, the "*ET_P40_2016_Apr-Oct*" image contains the the ET, ET_rF and ET_r for path 40 during the seasonal period April through October. The near real time provisional products had suffixes like "*_p3*" to indicate provisional products and the release number associated with the image set.

Figure 8 through Figure 14 show final monthly ET and ET_rF for April to October 2016 for paths 39 and 40. Figure 15 shows the final seasonal (April through October) ET and ET_rF for paths 39 and 40. These figures depict the information contained in the first and second bands of the various image sets.

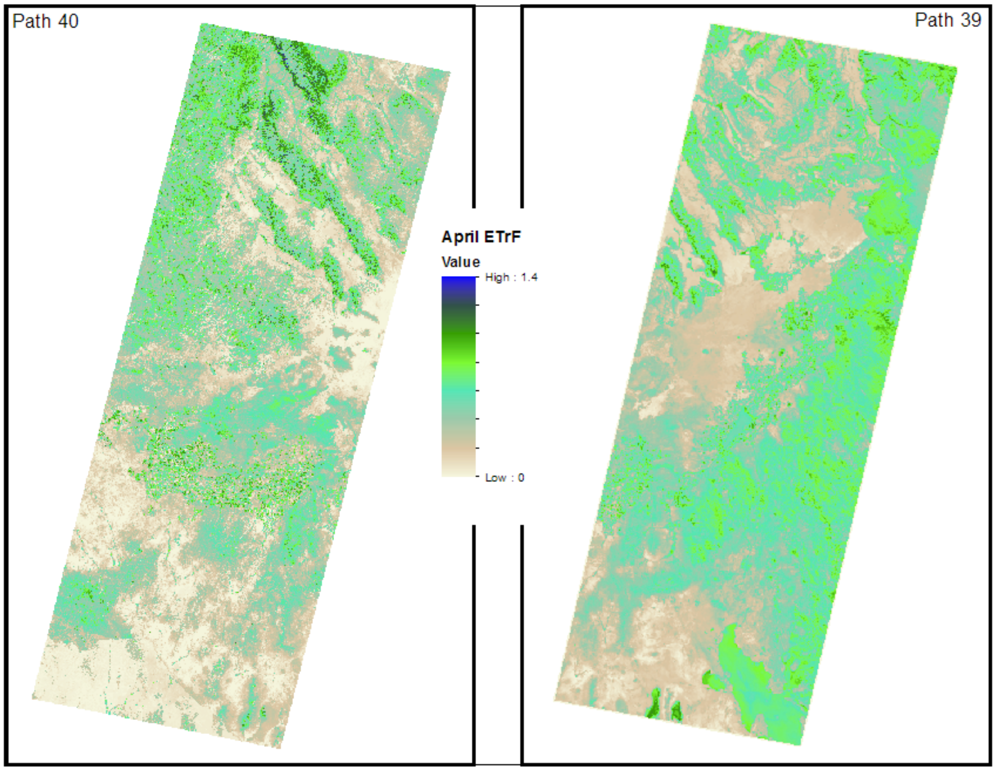


Figure 8a. April 2016 ET_rF (Final Product). Left: Path 40. Right: Path 39.

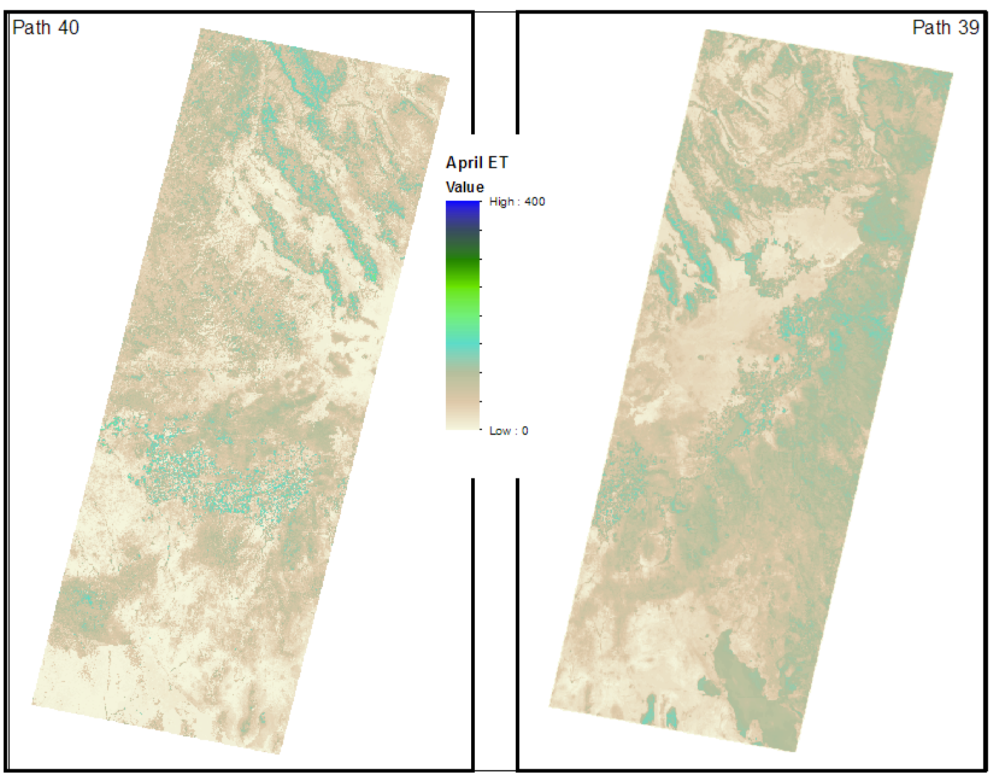


Figure 8b. April 2016 ET (Final Product). Left: Path 40. Right: Path 39.

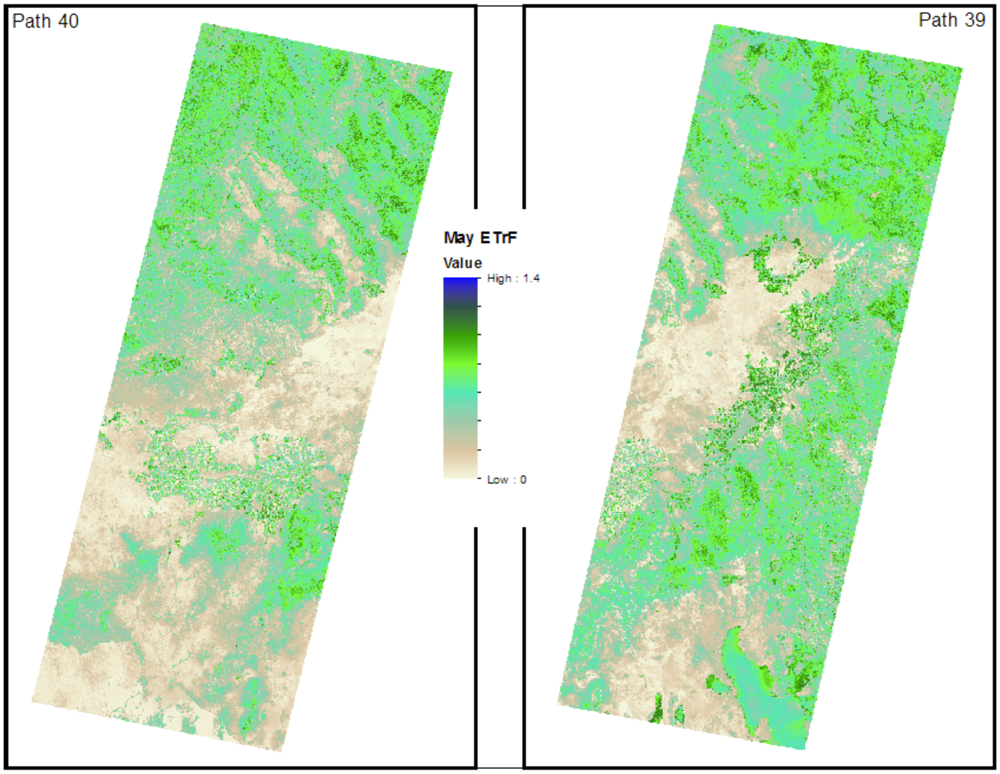


Figure 9a. May 2016 ET_rF (Final Product). Left: Path 40. Right: Path 39.

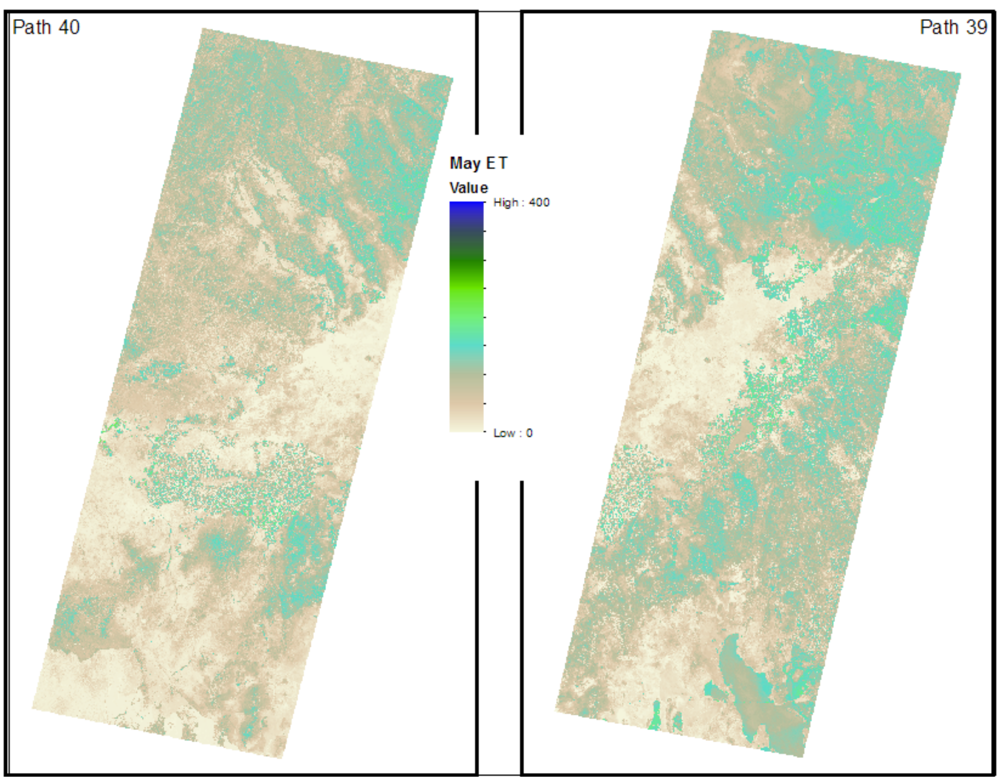


Figure 9b. May 2016 ET (Final Product). Left: Path 40. Right: Path 39.

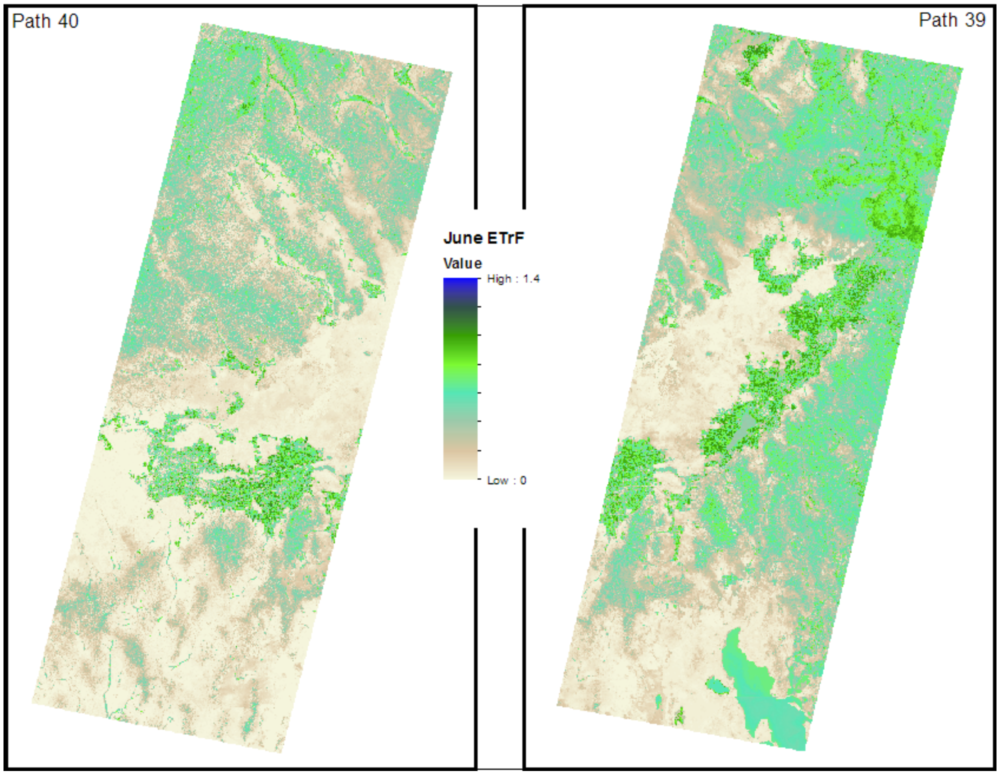


Figure 10a. June 2016 ET$_r$F (Final Product). Left: Path 40. Right: Path 39.

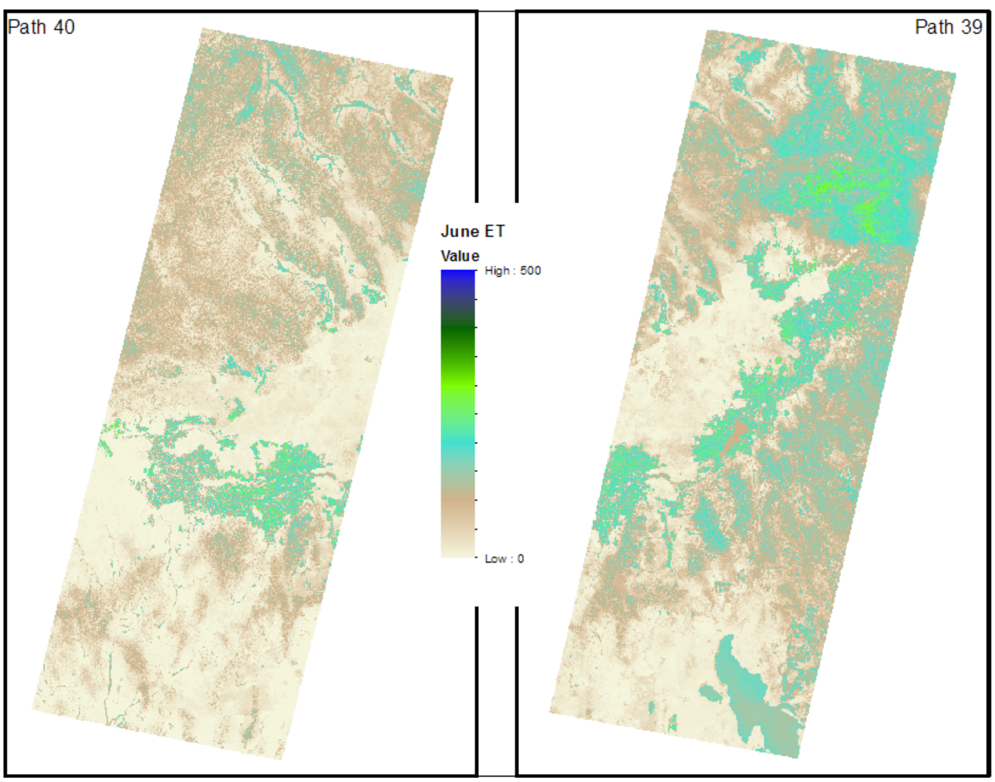


Figure 10b. June 2016 ET (Final Product). Left: Path 40. Right: Path 39.

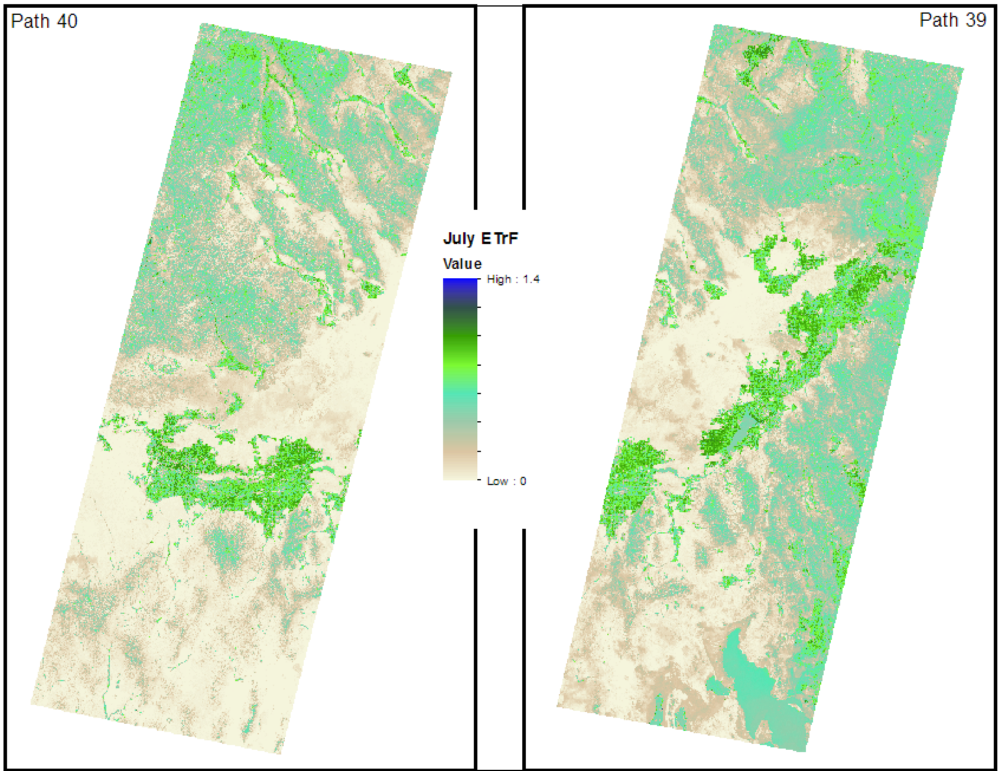


Figure 11a. July 2016 ET_rF (Final Product). Left: Path 40. Right: Path 39.

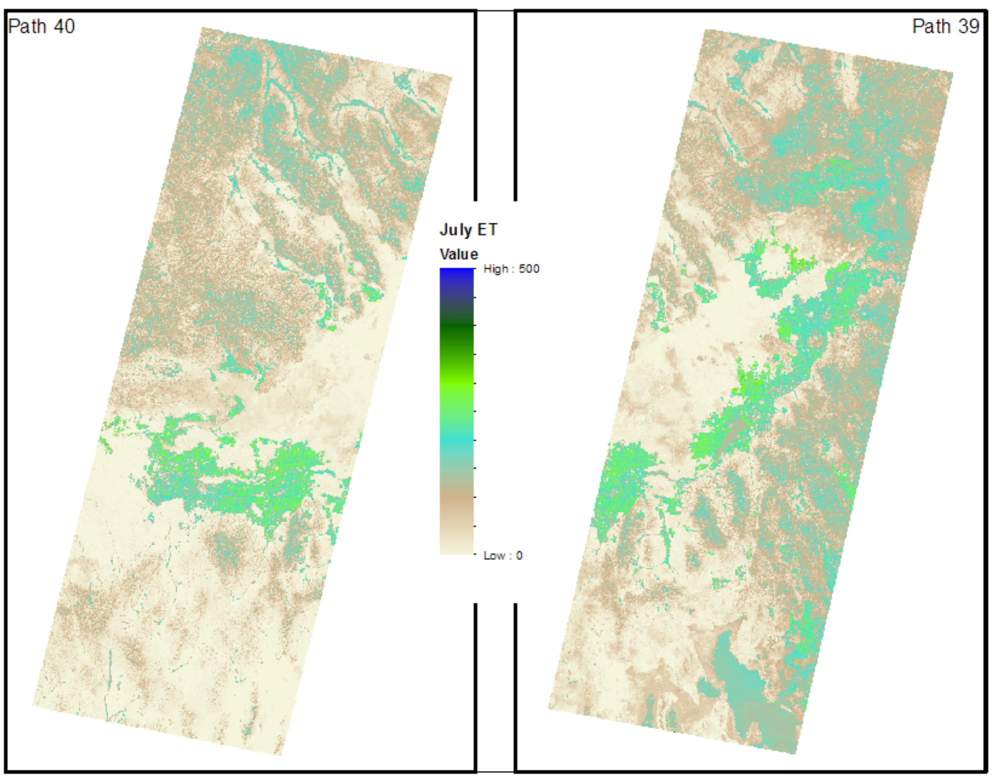


Figure 11b. July 2016 ET (Final Product). Left: Path 40. Right: Path 39.

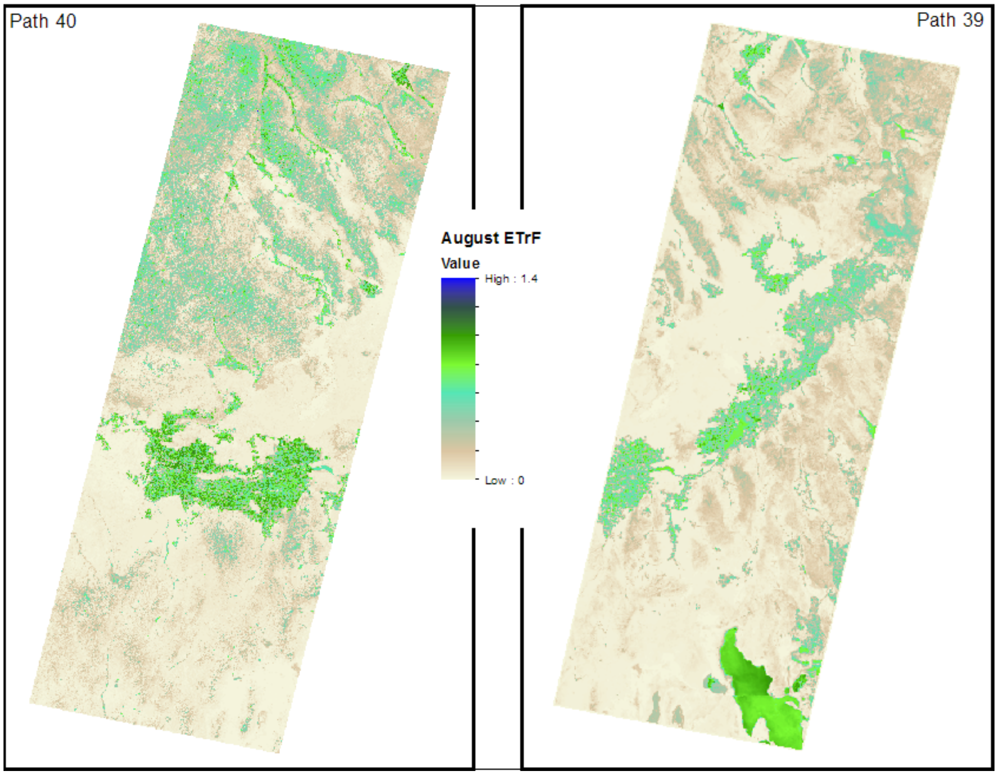


Figure 12a. August 2016 ET_rF (Final Product). Left: Path 40. Right: Path 39.

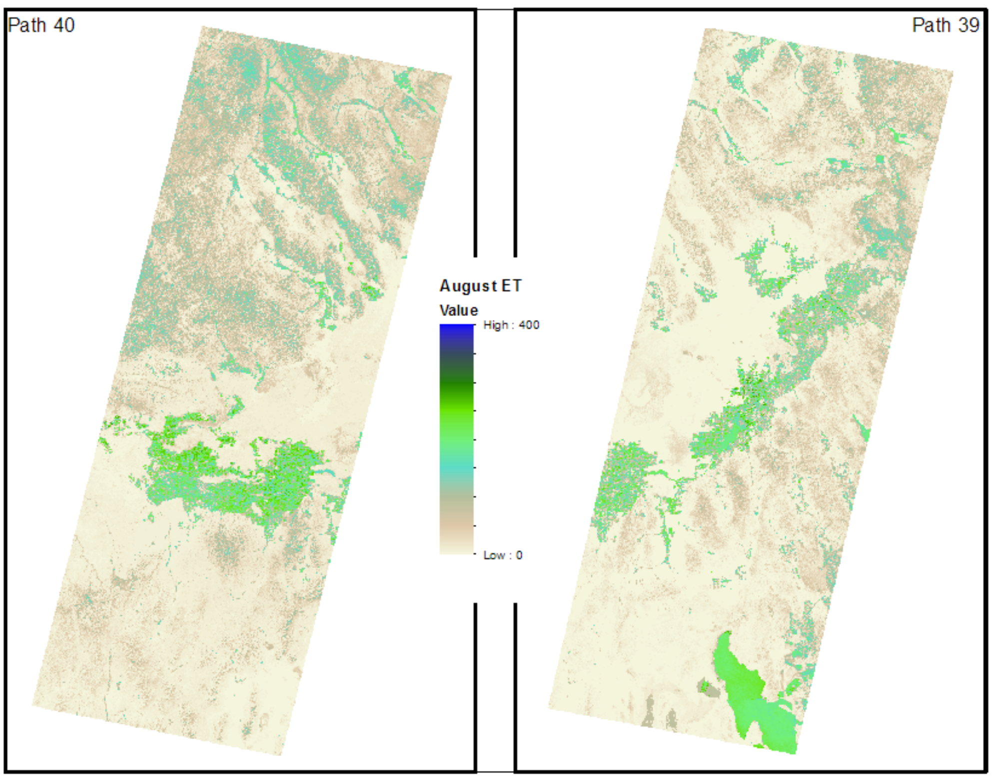


Figure 12b. August 2016 ET (Final Product). Left: Path 40. Right: Path 39.

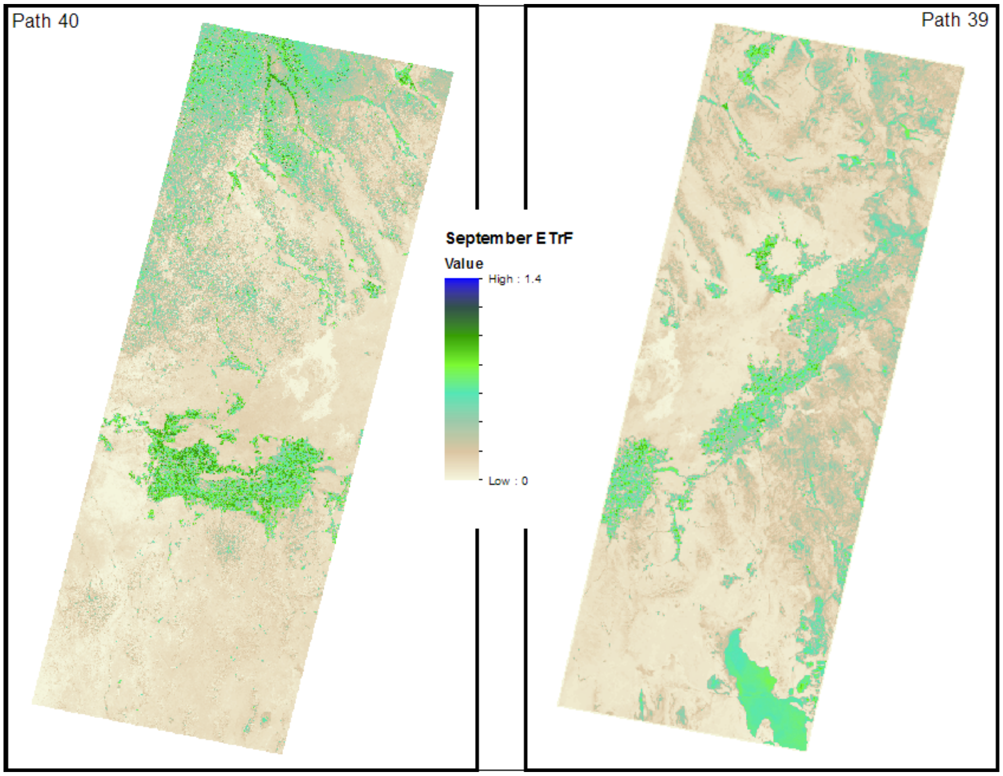


Figure 13a. September 2016 ET_rF (Final Product). Left: Path 40. Right: Path 39.

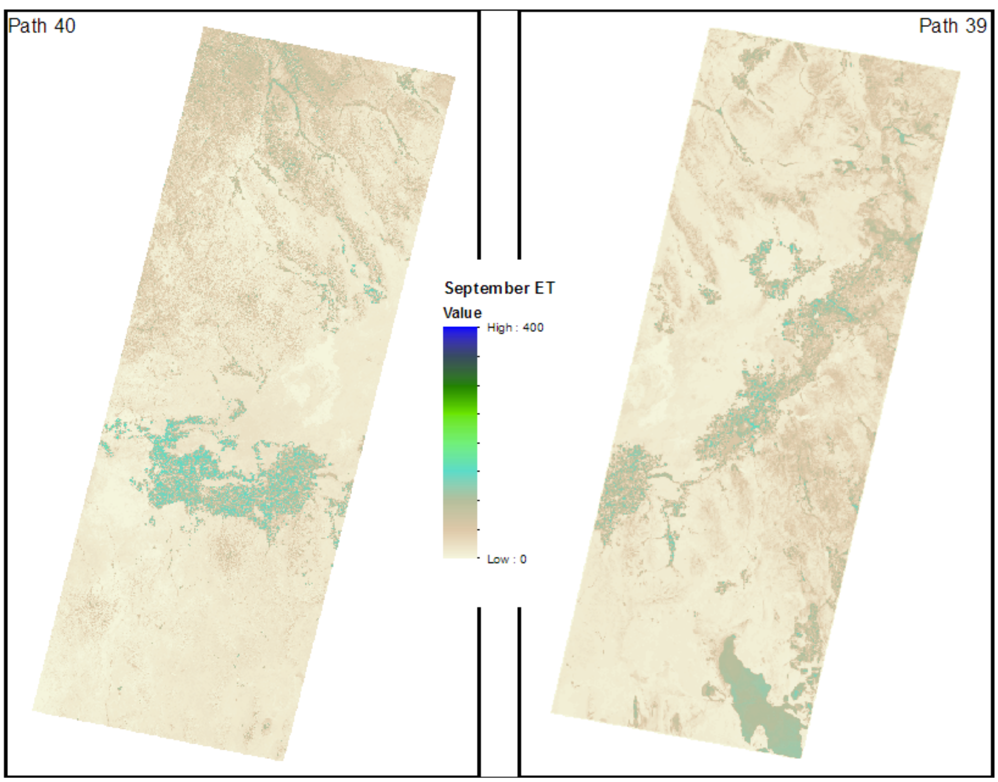


Figure 13b. September 2016 ET (Final Product). Left: Path 40. Right: Path 39.

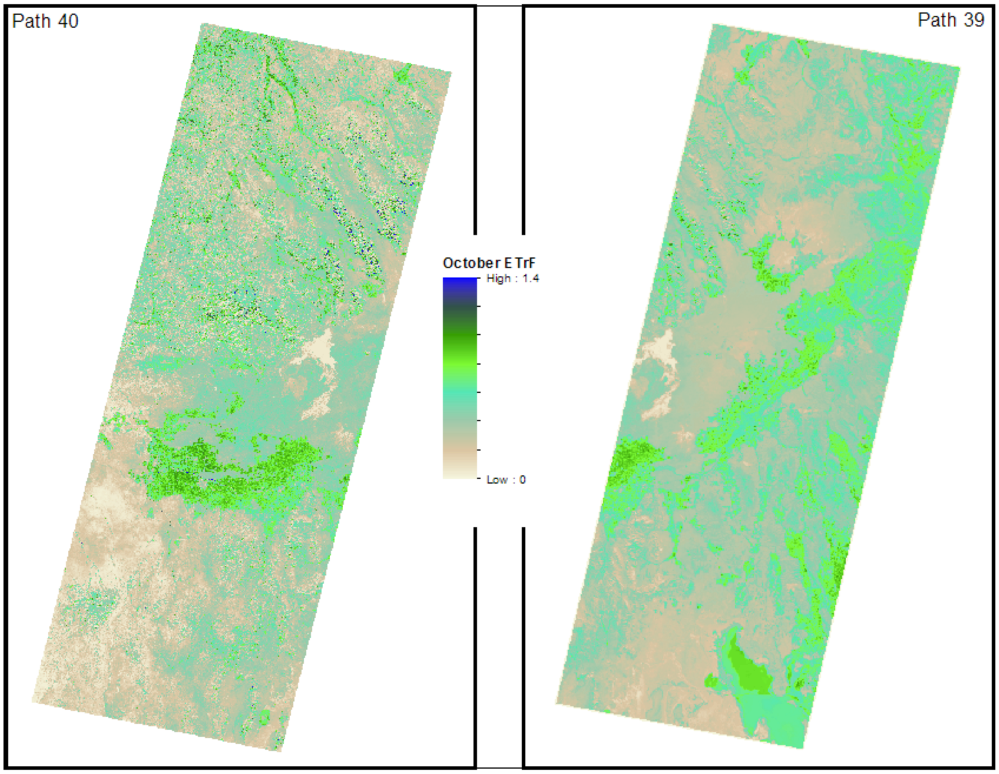


Figure 14a. October 2016 ET_rF (Final Product). Left: Path 40. Right: Path 39.

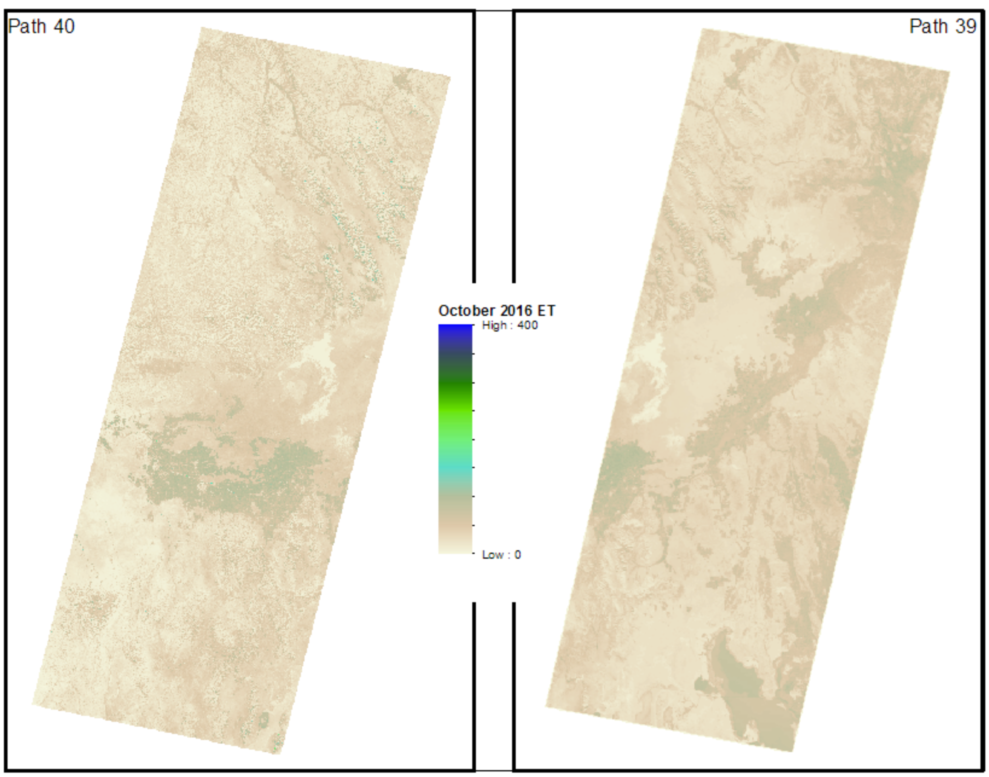


Figure 14b. October 2016 ET_rF (Final Product). Left: Path 40. Right: Path 39.

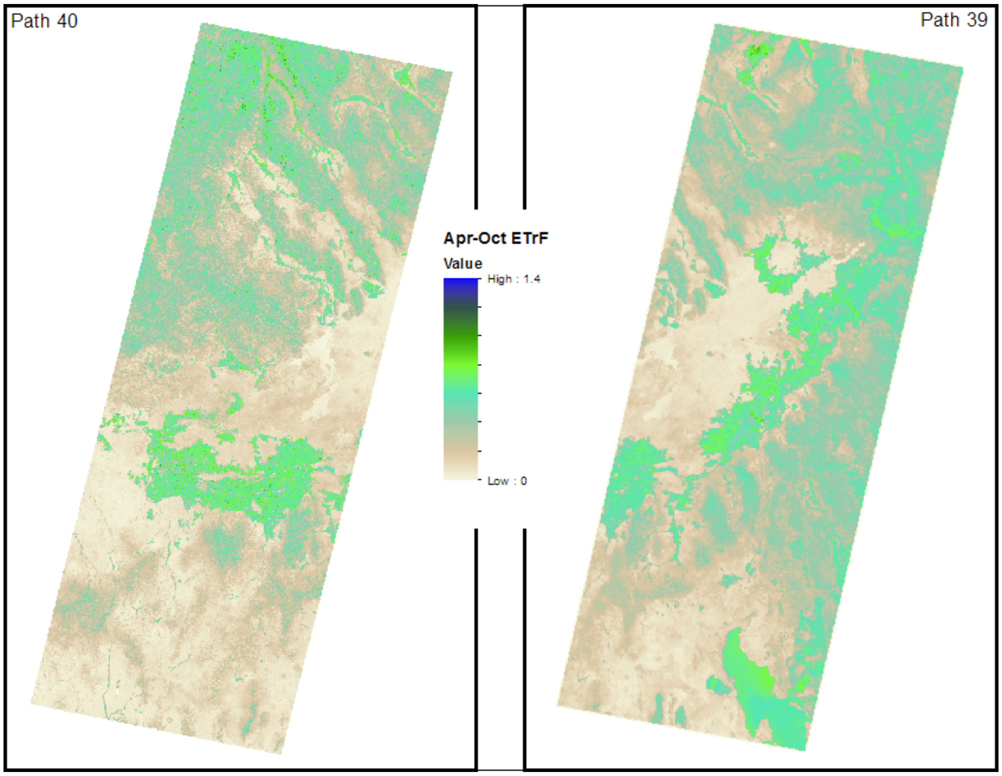


Figure 15a. April through October 2016 ET_rF (Final Product). Left: Path 40. Right: Path 39.

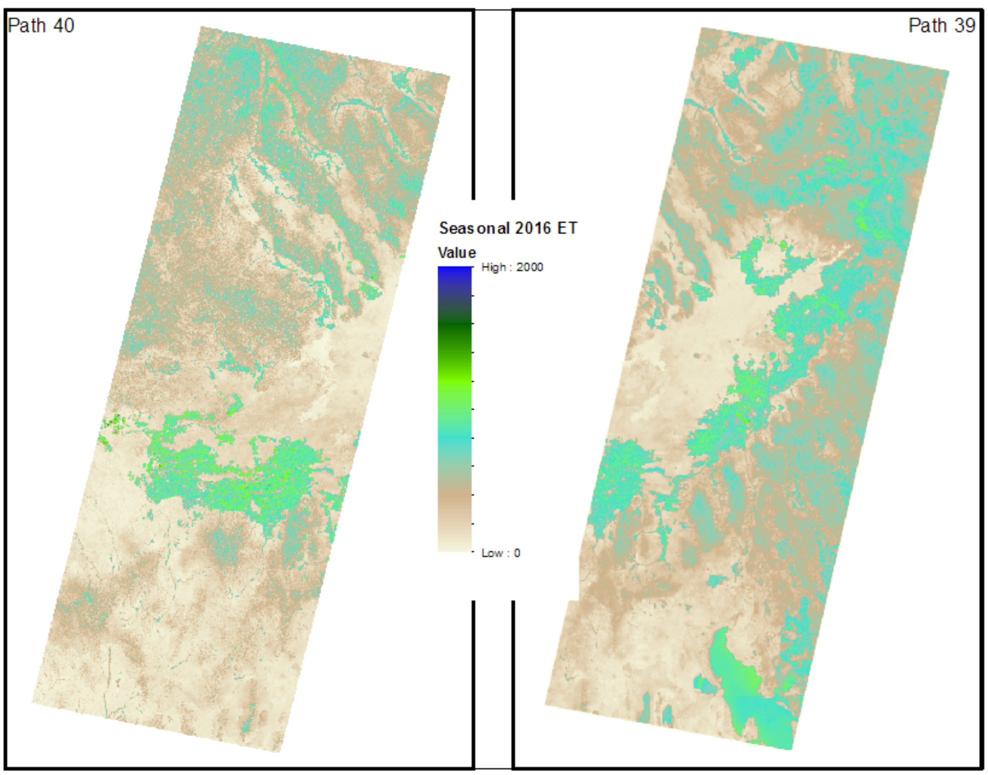


Figure 15b. April through October 2016 ET (Final Product). Left: Path 40. Right: Path 39.

7. Provisional and Final METRIC ET Products Comparison

To compare the provisional and final METRIC processing results, 8 irrigated areas and two non-irrigated areas were compared to each other as well as final results from 2010, 2011 and 2013. The ET products were used in the comparison. Figure 16 shows the 10 comparison areas (seasonal ET for 2016 is the background) and Table 4 further describes each area. The irrigated areas were based on the "Irrigation Organization" data layer found on the IDWR geospatial server as of January 20th, 2017. This shape file is commonly referred to as the "Permissible Place of Use". The two non-irrigated areas were hand digitized to represent rangeland (desert) and forested areas.

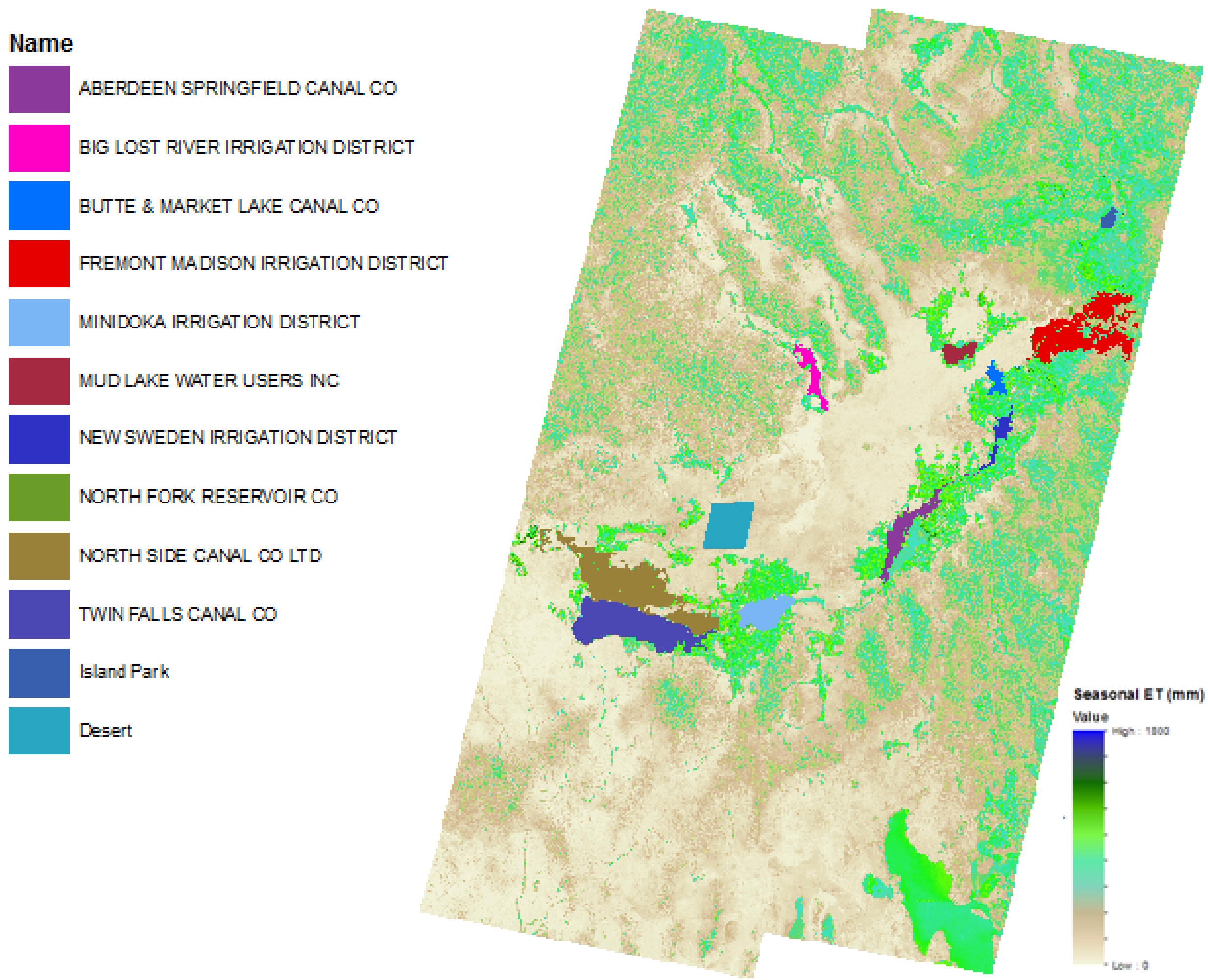


Figure 16. Areas used in comparison of ET products (Final Seasonal ET (MM) for 2016 is the back ground).

Two of the irrigation areas (Minidoka Irrig. Dist. and Big Lost River Irrig. Dist.) are covered by both path 39 and path 40 (overlap area) and were compared using both paths In the following tables and figures the results for those two areas have (P39) or (P40) as a suffix to indicate the source of the estimate. For the Big Lost River Irrig. Dist. the area was limited to the portion that was covered by both paths. The Fremont Madison Irrig. Dist area was limited to area with path 39. The "*Perimissable Place of Use*" includes irrigated and non-irrigated areas. In fact the "*Perimissable Place of Use*" of the organizations can overlap each other.

Table 4. General characteristics for the comparision areas.

Comparison Area	Path 39	Path 40	Acres
Aberdeen Springfield Canal Company	X		80343
Big Lost River Irrigation District	X	X	45330
Butte and Market Lake Canal Company	X		26604
Fremont Madison Irrigation District	X		248163
Minidoka Irrigation District	X	X	90402
Mud Lake Water Users Inc.	X		32716
New Sweden Irrigation District	X		31531
North Fork Reservoir Company	X		51552
North Side Canal Company		X	337435
Twin Falls Canal Company		X	271802
Island Park (Forest)	X		16636
Desert (Rangeland)		X	136491

Provisional and Final and Prior Years Seasonal ET

The average seasonal (Apr-Oct) ET for each region was compared using the provisional 2016, final 2016, 2010, 2011, and 2013 METRIC products. Table 5 shows the results and Figure 17 through Figure 28 visually depicits the seasonal ET for the region and the area associated with the region.

Table 5 Average Seasonal ET for the 10 comparison regions.

	Seasonal (Apr-Oct) ET (mm)				
Comparison Area	2016 Prov.	2016 Final	2013	2011	2010
Aberdeen Springfield Canal Co	868	878	900	815	824
Big Lost River Irrigation Dist (P39)	485	470	512	571	438
Big Lost River Irrigation Dist (P40)	504	509	487	502	492
Butte & Market Lake Canal Co	707	715	835	735	733
Fremont Madison Irrigation Dist.	683	653	751	666	585
Minidoka Irrigation Dist. (P39)	818	813	913	795	805
Minidoka Irrigation Dist. (P40)	808	888	892	820	828
Mud Lake Water Users Inc.	789	867	837	790	784
New Sweden Irrigation Dist.	747	773	923	765	798
North Fork Reservoir Co	751	733	785	682	672
North Side Canal Co	753	777	707	712	704
Twin Falls Canal Co	739	765	758	748	702
Island Park (Forest)	825	826	934	618	437
Desert (Rangeland)	238	202	91	122	287

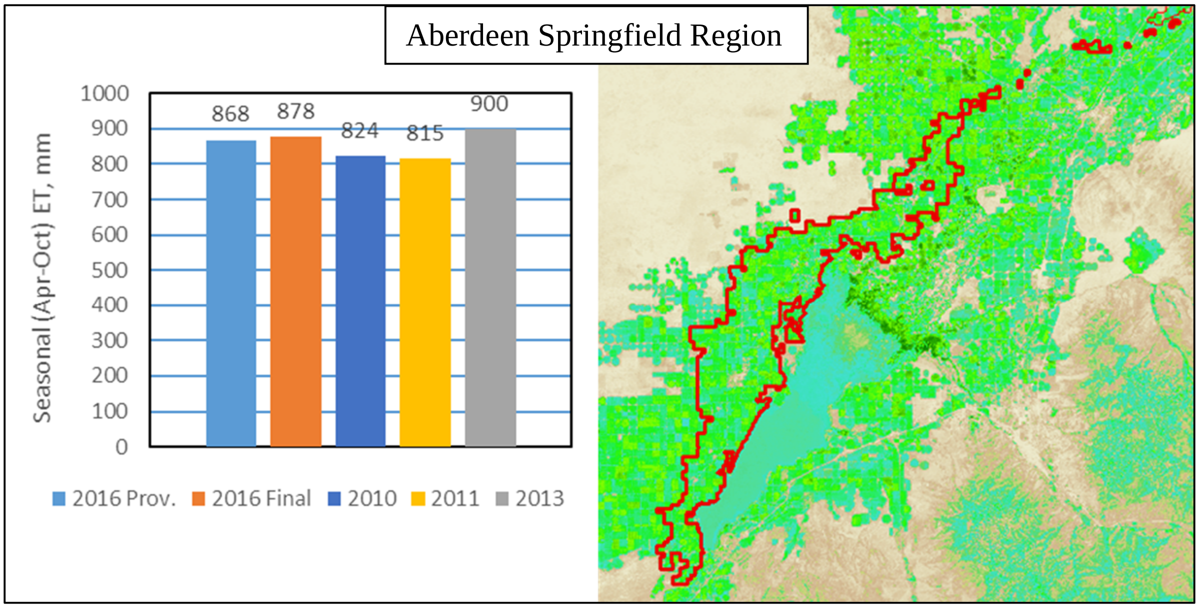


Figure 17. Average Apr-Oct ET for the Aberdeen Springfield region (area defining the region on the right)

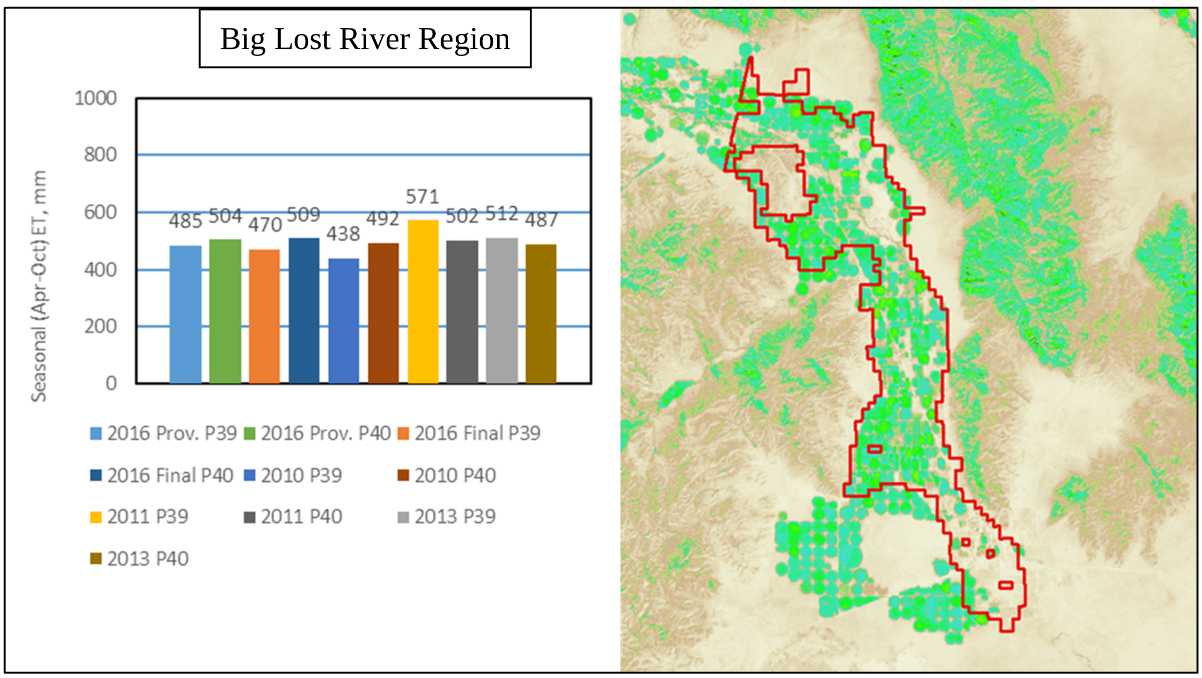


Figure 18. Average Apr-Oct ET for the Big Lost River region (area defining the region on the right). Seasonal ET shown for both processing paths.

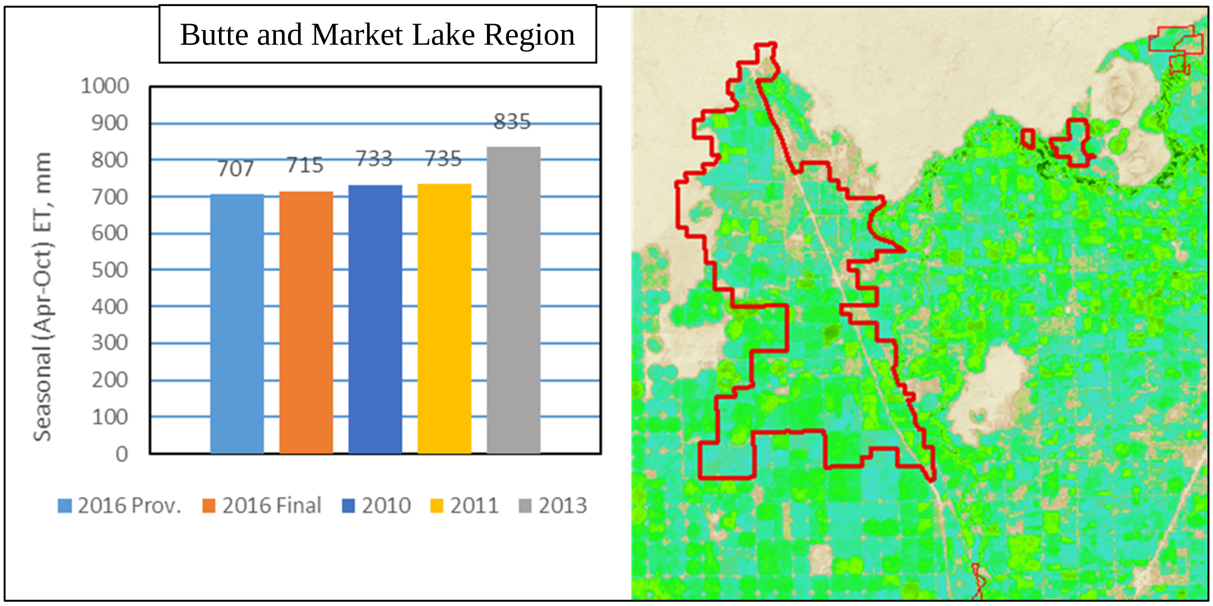


Figure 19. Average Apr-Oct ET for the Butte and Market Lake region (area defining the region on the right).

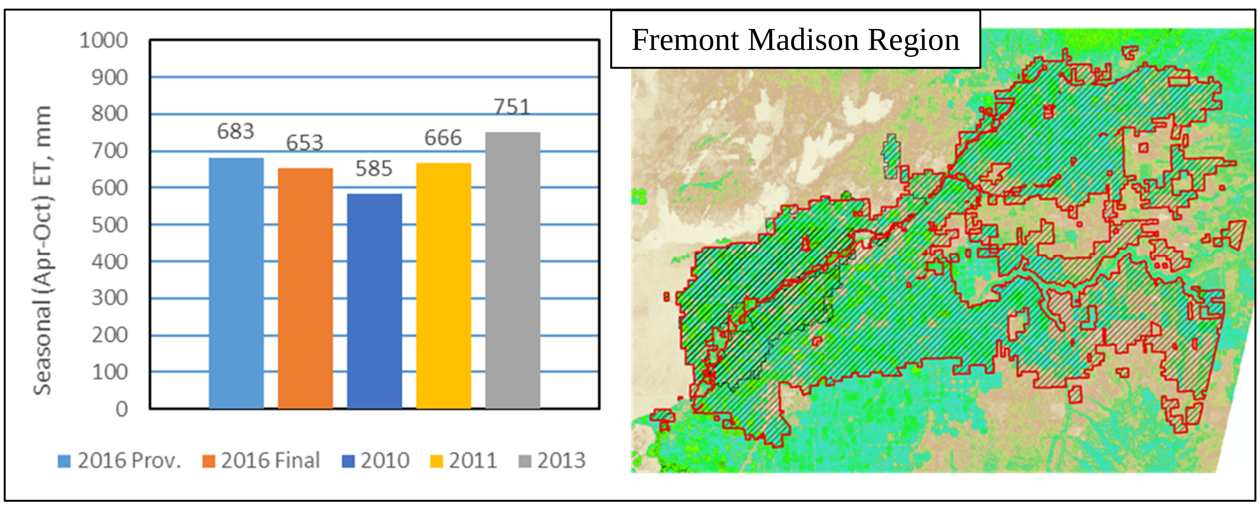


Figure 20. Average Apr-Oct ET for the Fremont Madison region (area defining the region on the right – area encompasses the North Fork region).

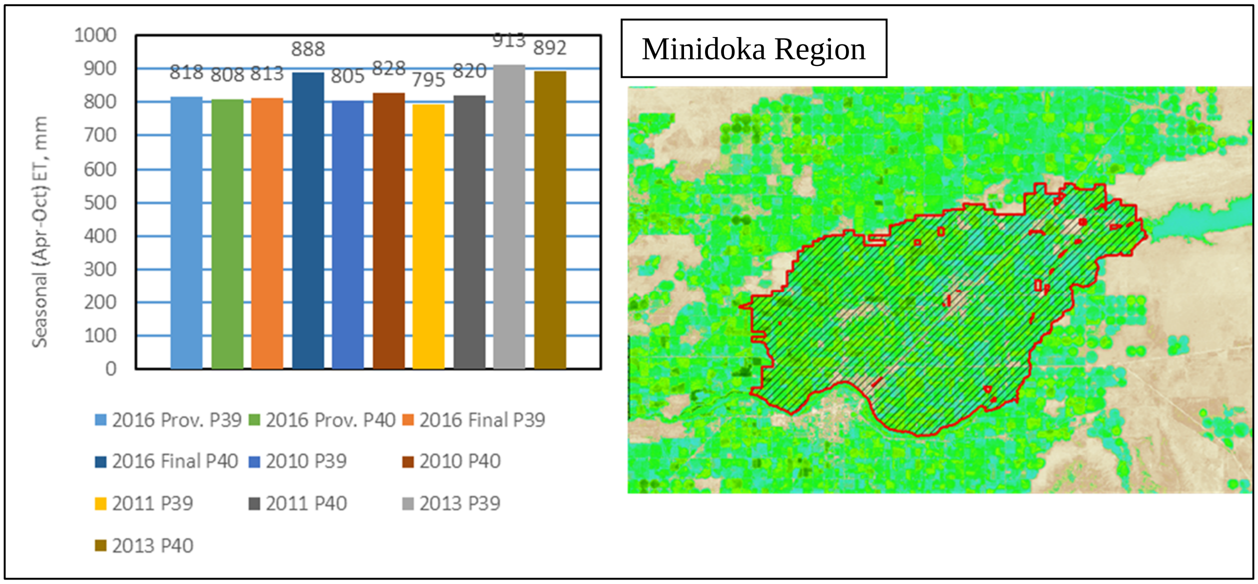


Figure 21. Average Apr-Oct ET for the Minidoka region (area defining the region on the right) Seasonal ET shown for both processing paths.

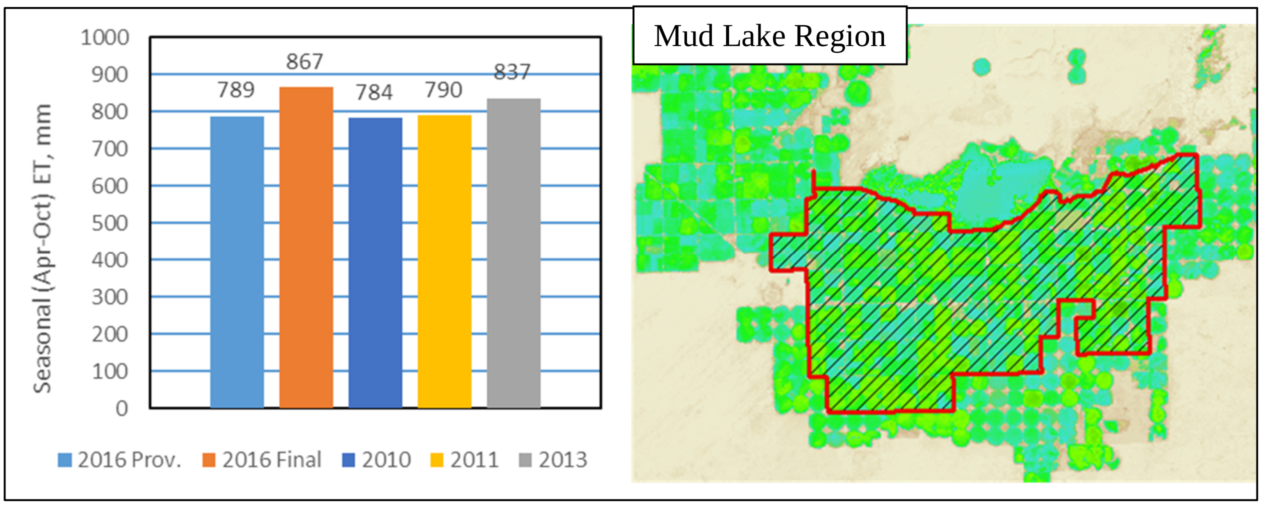


Figure 22. Average Apr-Oct ET for the Mud Lake region (area defining the region on the right).

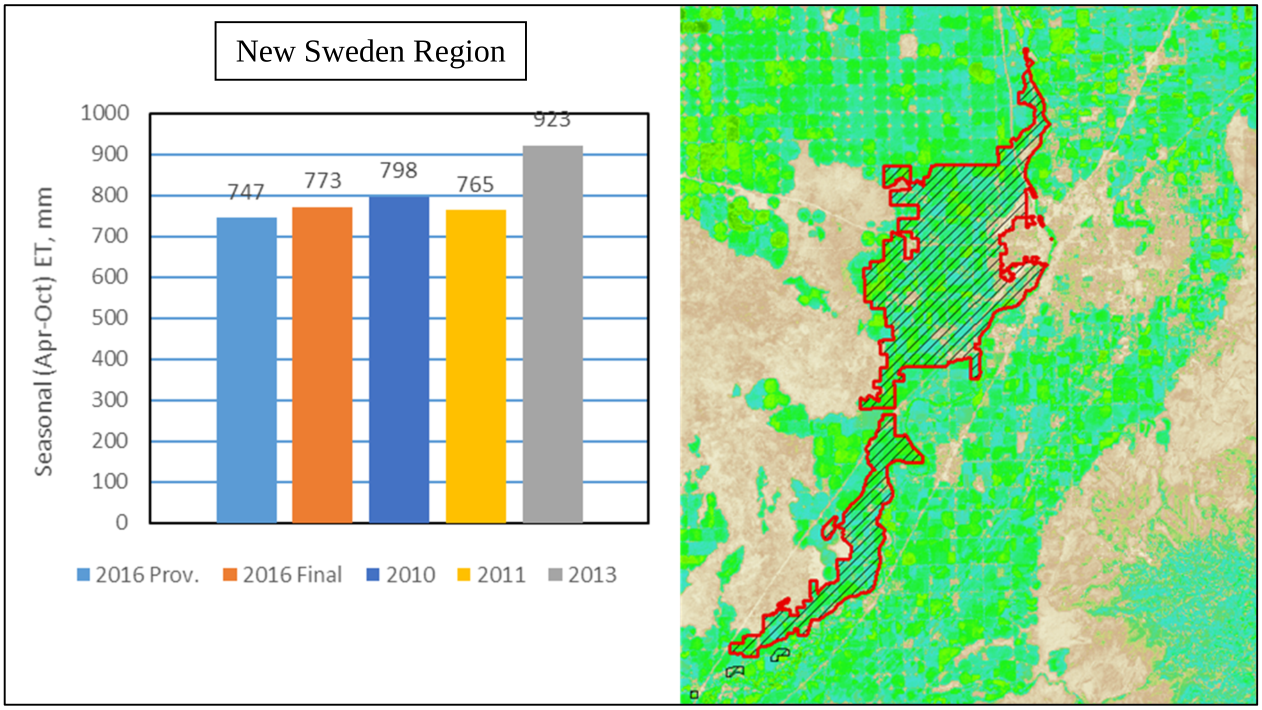


Figure 23. Average Apr-Oct ET for the New Sweden region (area defining the region on the right).

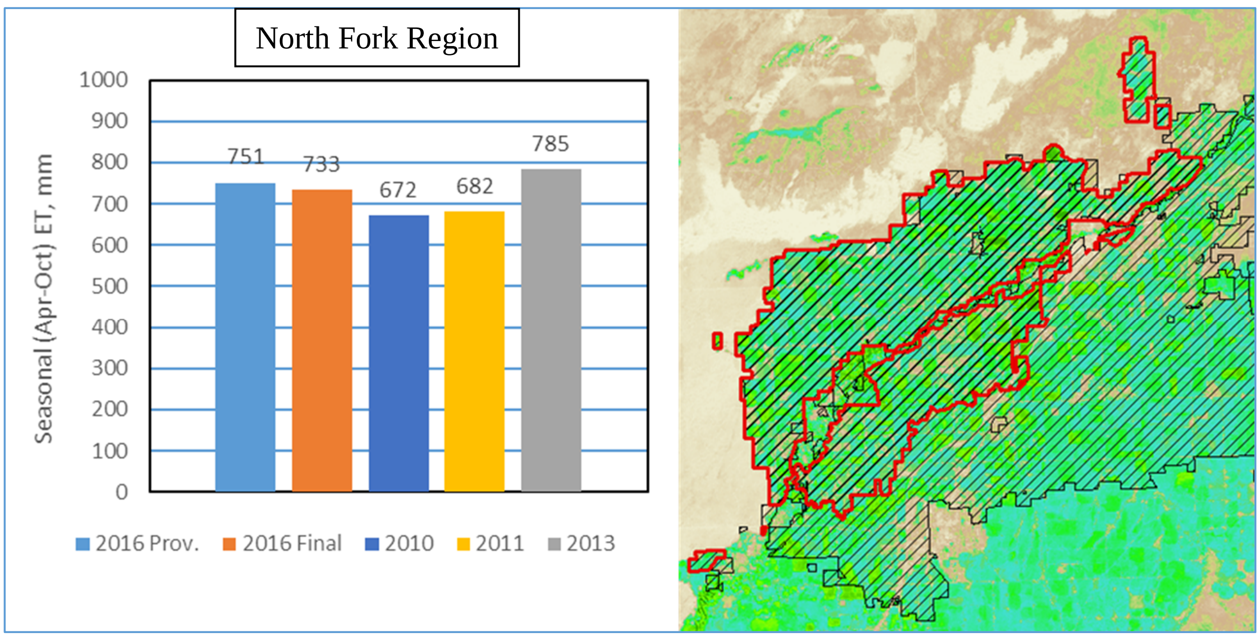


Figure 24. Average Apr-Oct ET for the North Fork region (area defining the region on the right). A majority of the area is also in the Fremon-Madison region.

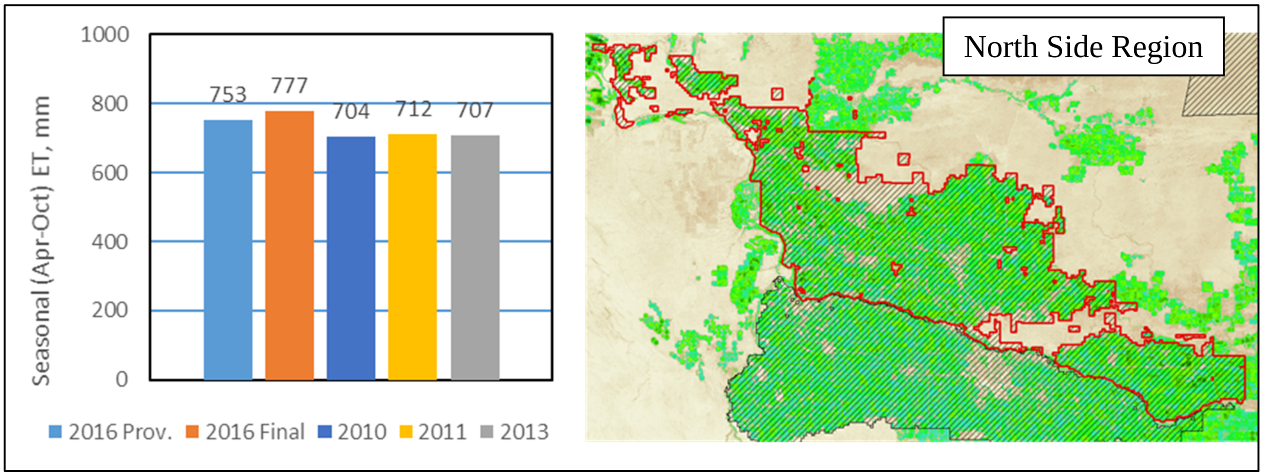


Figure 25. Average Apr-Oct ET for the North Side region (area defining the region on the right).

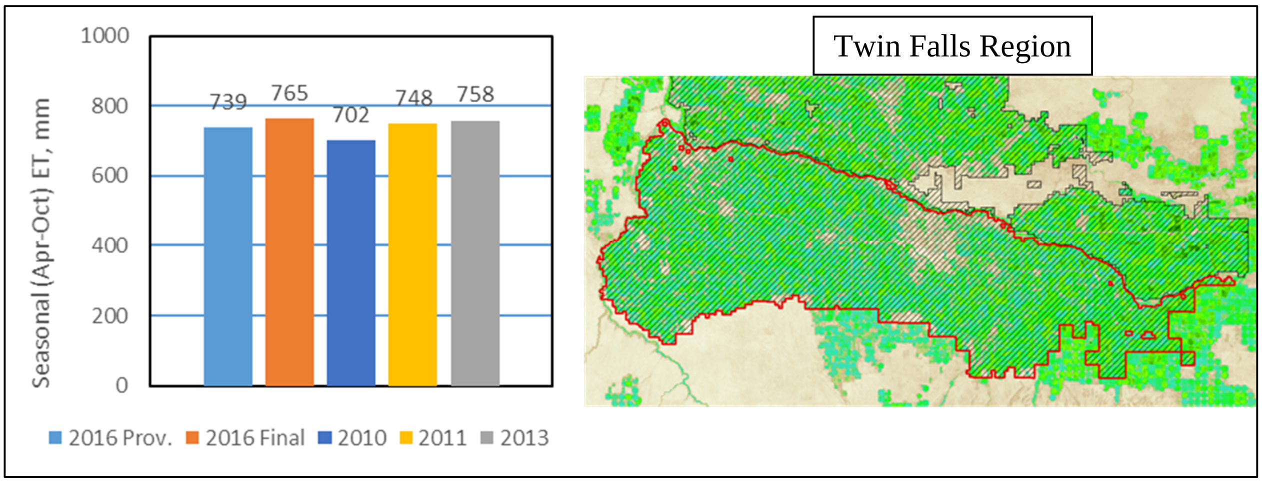


Figure 26. Average Apr-Oct ET for the Twin Falls region (area defining the region on the right).

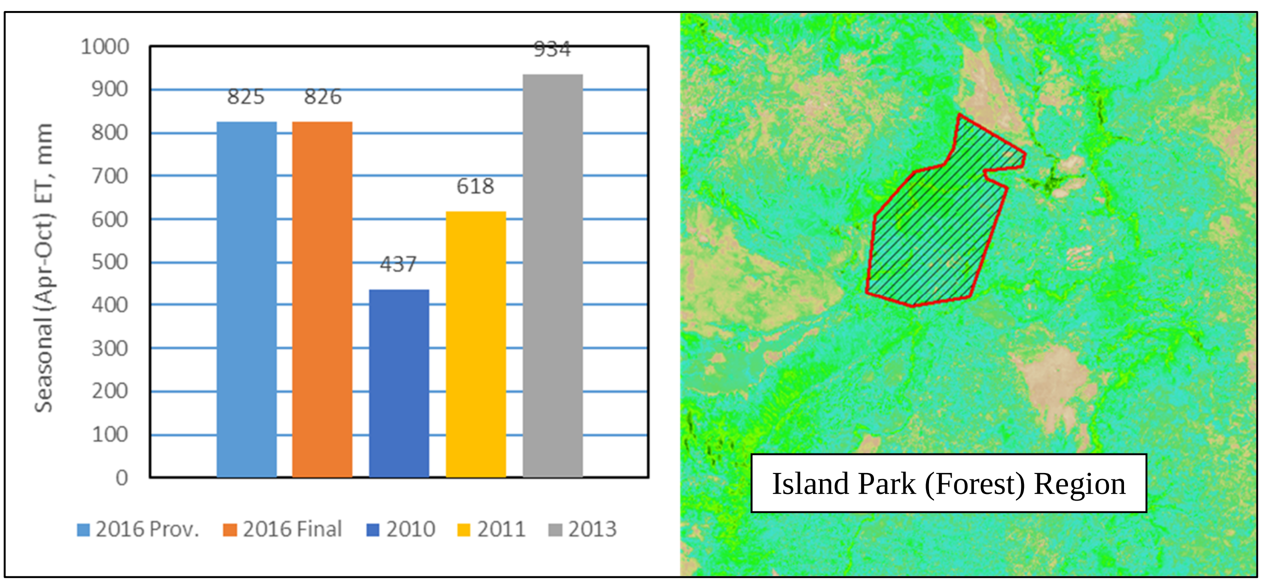


Figure 27. Average Apr-Oct ET for the Island Park (Forest) region (area defining the region on the right).

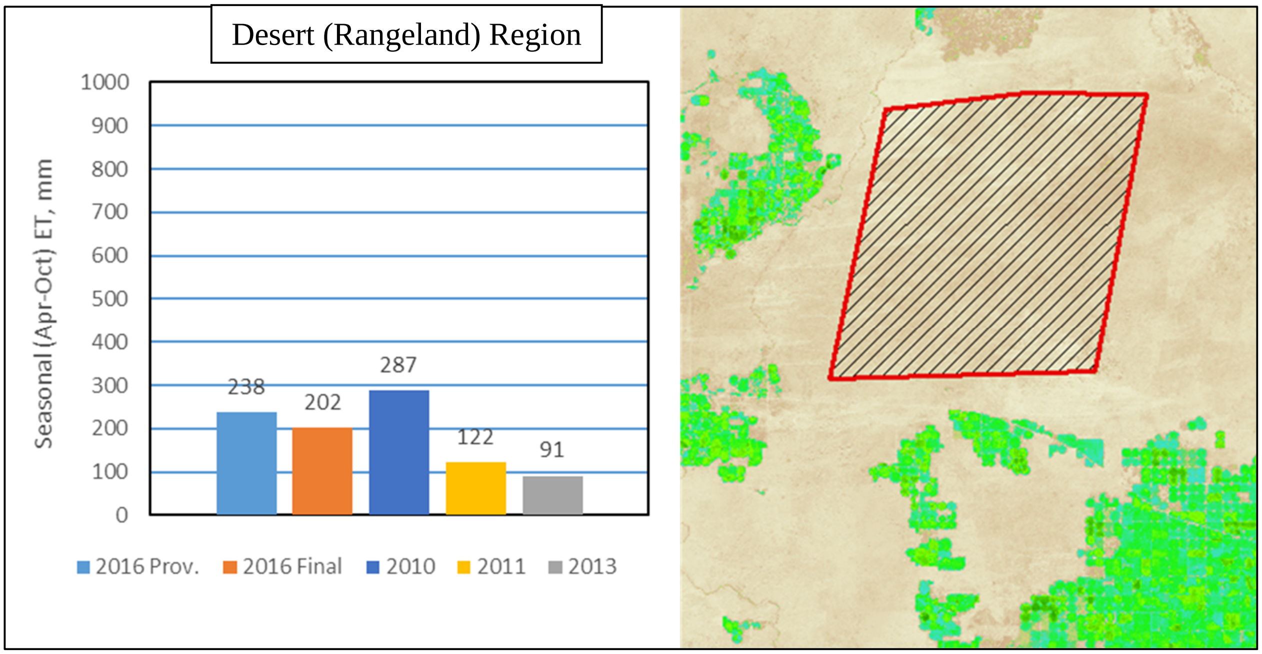


Figure 28. Average Apr-Oct ET for the Desert (Rangeland) region (area defining the region on the right).

Basically for all the areas the 2016 provisional and final ET products compare well to those products produced for the 2010, 2011 and 2013 seasons. When looking at the irrigated regions, for 7 of 10 comparisions, the final 2016 seasonal ET exceeded the provisional. The highest deviation was approximately 75 mm with a typical value of 24 mm. These values represent about 10 and 3% of typical growing season ET for irrigated crops. The North Fork region basically is a subset of the Fremont Madison region and has approximately 80 mm more ET for the 2016 products. One explaination is that the Fremont Madison region has more “non-irrigated” area as well as areas higher in elevation.

One explanation for the difference between provisional and final ET products are the differences in reference evapotranspiration (ET_r). Looking at the 2016 products for the “irrigated” regions, the provisional seasonal ET_r was 96% of the final ET_r, based on an area weighted average of the regions (Table 6) and ranged from 94% to 101%. The reference ET_r changed due to the application of QAQC procedures to the AWS weather data prior to calculation of ET_r for the final product. The QAQC process frequently adjusted solar radiation to account for over or under measurement.

These differences compare to a 99% provisional to final ET area weighted average for the “irrigated” regions (Table 7). The range of provisional to final ET for all the areas was 91% to 118% (desert). The early season (April through June) provisional to final ET for the “irrigated” areas was 91% based on an area weighted average. For those 10 irrigated areas the range was 75% to 103% as shown in Table 8.

Table 6. 2016 Provisional versus final seasonal ET_r comparison.

Comparison Area	Seasonal ETr (mm) Apr thru Oct 2016		
	Provisional	Final	% of Final
Aberdeen Springfield Canal Co	1361	1351	101%
Big Lost River Irrigation Dist (P39)	1293	1364	95%
Big Lost River Irrigation Dist (P40)	1293	1364	95%
Butte & Market Lake Canal Co	1304	1335	98%
Fremont Madison Irrigation Dist.	1302	1297	100%
Minidoka Irrigation Dist. (P39)	1292	1396	93%
Minidoka Irrigation Dist. (P40)	1292	1396	93%
Mud Lake Water Users Inc.	1274	1284	99%
New Sweden Irrigation Dist.	1251	1247	100%
North Fork Reservoir Co	1359	1369	99%
North Side Canal Co	1310	1387	94%
Twin Falls Canal Co	1252	1330	94%
Island Park (Forest)	1308	1369	96%
Desert (rangeland)	1316	1395	94%

Table 7. 2016 provisional versus final seasonal ET comparison.

Comparison Area	Seasonal ET (mm) Apr thru Oct 2016		
	Provisional	Final	% of Final
Aberdeen Springfield Canal Co	868	878	99%
Big Lost River Irrigation Dist (P39)	485	470	103%
Big Lost River Irrigation Dist (P40)	504	509	99%
Butte & Market Lake Canal Co	707	715	99%
Fremont Madison Irrigation Dist.	683	653	105%
Minidoka Irrigation Dist. (P39)	818	813	101%
Minidoka Irrigation Dist. (P40)	808	888	91%
Mud Lake Water Users Inc.	789	867	91%
New Sweden Irrigation Dist.	747	773	97%
North Fork Reservoir Co	751	733	102%
North Side Canal Co	753	777	97%
Twin Falls Canal Co	739	765	97%
Island Park (Forest)	825	826	100%
Desert (Rangeland)	238	202	118%

Table 8. April through June 2016 provisional versus final ET comparison.

Comparison Area	Period ET (mm) April through June 2016 Provisional	Final	% of Final
Aberdeen Springfield Canal Co	325	367	89%
Big Lost River Irrigation Dist (P39)	180	208	87%
Big Lost River Irrigation Dist (P40)	172	181	95%
Butte & Market Lake Canal Co	269	309	87%
Fremont Madison Irrigation Dist.	311	303	103%
Minidoka Irrigation Dist. (P39)	314	324	97%
Minidoka Irrigation Dist. (P40)	324	326	99%
Mud Lake Water Users Inc.	285	379	75%
New Sweden Irrigation Dist.	315	365	86%
North Fork Reservoir Co	325	331	98%
North Side Canal Co	241	269	90%
Twin Falls Canal Co	225	276	82%
Island Park (Forest)	447	474	94%
Desert (Rangeland)	172	116	148%

8. Summary

Provisional and final monthly evapotranspiration (ET) maps were produced for April, May, June, July, August, September and October 2016 in addition to an April-October summary. The products have 30 m resolution and cover Landsat WRS paths 39 and 40, rows 29, 30 and 31. ET was produced using the METRIC model (Mapping Evapotranspiration at high Resolution using Internalized Calibration) developed by the University of Idaho. The METRIC procedure utilizes visible, near-infrared and thermal infrared energy spectral bands from Landsat satellite images and weather data to calculate ET on a pixel by pixel basis. Surface energy is partitioned into net incoming radiation (both solar and thermal), ground heat flux, sensible heat flux to the air and latent heat flux. The latent heat flux is calculated as the residual of the energy balance and represents the energy consumed by ET.

The seasonal, April through October, provisional and final ET products compare well with each other, with the provisional being somewhat less than the final, overall. The April through June provisional and final ET products have more devivation from each other, with being typically 91% less.

To improve the early season April through June provisional products; the following items could be considered: improve the forecasting method; change the provisional interpolation process; and implement some of the meteorological quality control adjustments to the ET_r scripts.

For future near real time METRIC processing, a method or procedure to handle months having no acceptable Landsat images due to cloudiness needs to be developed.

References

Allen, R.G., 2008. REF-ET: Reference Evapotranspiration Calculation Software for FAO and ASCE Standardized Equations. University of Idaho, 82 pp. [http://www.kimberly.uidaho.edu/ref-et/index.html]. Contact author for updates.

Allen, R.G. and H. deBruin (2008). Calibration of the Slob net long wave radiation equation for reference ET conditions. draft paper, still in progress.

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop Evapotranspiration. Guidelines for computing crop water requirements. FAO Irrig. and Drain. Paper 56. FAO, Rome, 300 pp.

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., Wright, J.L., 2005. FAO-56 Dual Crop Coefficient Method for Estimating Evaporation from Soil and Application Extensions. J. Irrig. Drain. Engr., 131(1), 2-13.

Allen, R.G., Tasumi, M., Morse, A., Trezza, R., Wright, J.L., Bastiaanssen, W., Kramber, W., Lorite, I., Robison, C.W., 2007a. Satellite-Based Energy Balance for Mapping Evapotranspiration with Internalized Calibration (METRIC) – Applications. J. Irrig. Drain Engr., 133(4), 395-406.

Allen, R.G., Tasumi, M., Trezza, R., 2007b. Satellite-Based Energy Balance for Mapping Evapotranspiration with Internalized Calibration (METRIC) – Model. J. Irrig. Drain Engr., 133(4), 380-394.

Allen, R.G., Trezza, R., Tasumi, M., Kjaersgaard, J.H., 2014. METRIC. Mapping Evapotranspiration at High Resolution. Applic. Manual, V 3.0. University of Idaho. 279 pp.

Allen, R.G., J.H. Kjaersgaard, R. Trezza, A. Oliveira, C. Robison, I. Lorite-torres. 2011. Refining components of a satellite based surface energy balance model to complex-land use systems. Proceedings of Remote Sensing and Hydrology 2011 Symposium held at Jackson Hole, Wyoming, USA, September 2011, IAHS Publ. 3XX, 2011. 3 p.

ASCE-EWRI, 2005. The ASCE Standardized Reference Evapotranspiration Equation. ASCE, Reston, Virginia.

Bastiaanssen, W. G. M., Menenti, M., Feddes, R. A., and Holtslag, A. A. M. (1998a). "A remote sensing surface energy balance algorithm for land (SEBAL): 1. Formulation." J. Hydrol., 212–213, 198–212.

Bastiaanssen, W. G. M., Pelgrum, H., Wang, J., Ma, Y., Moreno, J., Roerink, G. J., and van der Wal, T. (1998b). "A remote sensing surface energy balance algorithm for land (SEBAL): 2. validation." J. Hydrol., 212–213, 213–229.

Bastiaanssen , W.G.M., E.J.M. Noordman , H. Pelgrum, G. Davids, B.P. Thoreson and R.G. Allen. 2005. SEBAL model with remotely sensed data to improve water resources management under actual field conditions. J. Irrig. and Drain. Engrg, ASCE 131(1): 85-93.

Chávez, J., C.M.U. Neale, J.H. Prueger, W.P. Kustas. 2008. Daily evapotranspiration estimates from extrapolating instantaneous airborne remote sensing ET values. Irrigation Science Volume 27, Issue 1, pp 67-81

Chen, J., X Zhu, JE Vogelmann, F Gao, S Jin, 2011. A simple and effective method for filling gaps in Landsat ETM+ SLC-off images. Remote Sensing of Environment, 1053-64.

Colaizzi, P. D., S. R. Evett, T. A. Howell, J. A. Tolk. 2006. Comparison of Five Models to Scale Daily Evapotranspiration from One-Time-of-Day Measurements. Transactions of the ASABE. 49(5): 1409-1417. .

Kjaersgaard, J. and R.G. Allen. 2011. Calibration of the Slob net long wave radiation equation using surface temperature from dry surfaces. draft report/paper, still in progess.

Kjaersagaard, J. and R.G. Allen. 2011. Remote Sensing Technology to Produce Consumptive Water Use Maps for the Nebraska Panhandle. Final completion report submitted to the University of Nebraska. 60 pages.

Kjaersgaard, J. and R.G. Allen. 2011. Processing Landsat imagery to Produce Consumptive Water Use Maps in North-East Colorado. , University of Idaho, Kimberly, Idaho. Report Submitted to Riverside Technology, Inc, Ft. Collins, Colorado, September 2011. 74 pages.

Trezza, R., Allen, R.G., Garcia, M., Kjaersgaard, J.H. (2008). “Using a Cubic Spline to Interpolate between Images.” University of Idaho, Kimberly, Idaho. 9 pp.

Trezza, R., R.G. Allen, C.W. Robison, W.J. Kramber, J. Kjaersgaard, M. Tasumi, M. Garcia. 2008. Enhanced Resolution of Evapotranspiration from Riparian Systems and Field Edges by Sharpening the Landsat Thermal Band. Paper presented at the 2008 World and Environmental Resources Congress of ASCE and EWRI, Honolulu, HI, May 12-16, 2008. Published on CD-ROM, ASCE. 12 p.

Wright, J.L., 1982. New evapotranspiration crop coefficients. J. Irrig. Drain. Engr., 108(1), 57-74.

Appendix A: Automatic Weather Station Meteorological Daily Data

The meteorological data for determining daily ET_r, K_e (bare soil evaporation coefficient), and for assessing green up conditions were comprised of daily data collected at automated weather stations operated by USBR, DRI, USU, NOAA/INL, and UDSA/USDI. These stations are part of Agrimet networks operated by the USBR Pacific Northwest Region, USBR Great Plains Region and NOAA/INL. The USU stations are part of the UCC-AgNet network which USBR/PN is a partner with and data from those stations are available through the USBR Agrimet-system. The DRI and HADS station network in Northern Nevada is operated by DRI. The data for these stations will ultimately be available through Agrimet; however, that is not currently the case. The data for these stations as well as the stations in the RAWS network were downloaded from MesoWest and summarized into daily summaries. The USDA and USDI operate a RAWS network of automated weather stations primarily for fire weather products. Initially 67 stations were identified, and for the provisional processing, 66 stations (Table 9) were used.

Table 9. Automated Weather Stations used in interpolation processes and location parameters and soil characteristics from Web Soil Survey[1].

ID	Name	Network	Latitude (Deg)	Longitude (Deg)	Elevation (m)	Uz (m)	Soil Surface Characteristics: Depth (mm)	Field Capacity	Wilting Point	REW (mm)
ABEI	Aberdeen, ID	INL	42.95333	-112.82667	1341.0	2	150	0.269	0.108	10.9
ACKI	Blackfoot, ID	INL	43.18985	-112.33320	1377.7	15	150	0.205	0.090	9.0
AFTY	Afton, WY	PN	42.73333	-110.93583	1892.8	3	150	0.269	0.121	11.0
AHTI	Ashton, ID	PN	44.02500	-111.46666	1615.4	3	150	0.281	0.117	11.3
BKVO	Baker Valley, OR	PN	44.88277	-117.96277	1042.4	3	150	0.272	0.106	11.2
BLCU	Blue Creek, UT	UCC	41.96217	-112.49117	1575.8	3	150	0.267	0.117	11.3
BOII	Boise, ID	PN	43.60027	-116.17694	829.1	3	150	0.290	0.119	11.5
BOZM	Bozeman, MT	GP	45.67302	-111.15462	1455.4	2	150	0.300	0.139	11.5
COVM	Corvallis, MT	PN	46.33333	-114.08333	1096.4	3	150	0.274	0.121	11.1
CRNU	Corinne, UT	UCC	41.51915	-112.17395	1291.7	3	150	0.300	0.147	11.4
DENI	Dworshak, ID	PN	46.62333	-116.22055	499.9	3	150	0.385	0.165	13.3
DLNM	Dillon, MT	GP	45.33358	-112.50939	1524.0	2	150	0.202	0.083	9.0
DRLM	Deer Lodge, MT	PN	46.33555	-112.76666	1426.5	3	150	0.295	0.138	11.1
DWNI	Downey, ID	PN	42.43355	-112.12929	1483.0	3	150	0.244	0.083	10.7
EURN	Eureka, NV	PN	39.68527	-115.97861	1797.4	3	150	0.181	0.069	8.7
EVFU	Evan\'s Farm, UT	UCC	41.69450	-111.83317	1382.3	3	150	0.293	0.144	11.0
EVTY	Evanston, WY	PN	41.19713	-111.02937	2080.0	3	150	0.286	0.132	11.0
FAFI	Fairfield, ID	PN	43.31305	-114.82222	1535.6	3	150	0.283	0.136	10.9
FTHI	Fort Hall, ID	PN	43.07138	-112.43111	1354.8	3	150	0.140	0.053	6.8
GDVI	Grand View, ID	PN	42.91250	-116.05611	786.4	3	150	0.208	0.083	9.9
GFRI	Glenns Ferry, ID	PN	42.86666	-115.35694	922.0	3	150	0.221	0.104	9.2
GREI	Grace, ID	PN	42.51496	-111.73606	1661.0	3	150	0.250	0.100	8.0
GRTU	Grantsville, Utal	PN	40.53054	-112.75653	1331.0	3	150	0.217	0.093	10.0
HAMI	Hamer, ID	INL	44.00742	-112.23883	1476.1	15	150	0.105	0.033	5.5
ICHI	Richfield, ID	INL	43.06060	-114.13458	1328.3	15	150	0.268	0.110	11.1
IFAI	ID Falls, ID	INL	43.50413	-112.05013	1435.3	15	150	0.269	0.092	11.3
KTBI	Kettle Butte, ID	INL	43.54861	-112.32583	1565.0	2	150	0.269	0.091	11.3
LAKU	Laketown, UT	UCC	41.83790	-111.33438	1816.3	3	150	0.275	0.124	11.1
LEWU	Lewiston, UT	UCC	41.95213	-111.86903	1375.9	3	150	0.228	0.109	9.3
MALI	Malta, ID	PN	42.43750	-113.41388	1344.2	3	150	0.257	0.089	11.1

[1] USDA/NRSC Web Soil Survey (http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx). Soil surface characteristic determined by areal weighting of soil information in the vicinity of each automated weather station reported location. Data accessed during March 1 through March 15, 2016.

ID	Name	Network	Latitude (Deg)	Longitude (Deg)	Elevation (m)	Uz (m)	Soil Surface Characteristics Depth (mm)	Field Capacity	Wilting Point	REW (mm)
MDKI	Minidoka, ID	INL	42.80442	-113.58965	1306.1	15	150	0.256	0.086	11.1
MNPI	Montpelier, ID	PN	42.25452	-111.33773	1823.0	3	150	0.424	0.216	13.7
MNTI	Monteview, ID	INL	44.01500	-112.53583	1480.0	2	150	0.224	0.101	9.3
NMPI	Nampa, ID	PN	43.43722	-116.64527	823.6	3	150	0.253	0.095	10.9
ONTO	Ontario, OR	PN	43.97777	-117.01527	688.9	3	150	0.261	0.092	11.1
OSGI	Osgood, ID	PN	43.58884	-112.07568	1471.0	3	150	0.269	0.091	11.3
OWEI	Howe, ID	INL	43.78412	-112.97732	1467.5	15	150	0.299	0.132	11.6
PICI	Picabo, ID	PN	43.31166	-114.16583	1493.5	3	150	0.302	0.138	11.6
PMAI	Parma, ID	PN	43.80000	-116.93333	702.6	3	150	0.277	0.108	11.3
PSTI	Preston, ID	PN	42.10715	-111.89363	1335.0	3	150	0.332	0.169	11.9
RBYM	Ruby River Valley, MT	GP	45.34475	-112.15029	1600.2	2	150	0.271	0.129	10.7
RGBI	Rigby, ID	PN	43.67720	-111.87922	1488.0	3	150	0.206	0.078	9.7
ROBI	Roberts, ID	INL	43.74352	-112.12112	1450.8	15	150	0.328	0.193	11.8
RPTI	Rupert, ID	PN	42.59555	-113.87388	1266.4	3	150	0.278	0.108	11.4
RRII	Ririe, ID	PN	43.61034	-111.70060	1547.0	3	150	0.267	0.108	11.1
RRCI	Arco, ID	INL	43.62455	-113.29710	1627.3	15	150	0.278	0.108	11.4
RTHI	Rathdrum Parrie, ID	PN	47.80000	-116.83333	673.6	3	150	0.178	0.042	9.7
RXGI	Rexburg, ID	PN	43.85000	-111.76666	1485.9	3	150	0.330	0.166	11.9
SHLI	Shelley, ID	PN	43.43452	-112.14273	1417.0	3	150	0.246	0.096	10.4
SNWU	Snowville (West), UT	UCC	41.98382	-112.91198	1354.2	3	150	0.287	0.122	11.4
SUGI	Sugar City, ID	INL	43.89658	-111.73762	1492.0	15	150	0.251	0.125	9.7
TABI	Taber, ID	INL	43.31868	-112.69180	1441.7	15	150	0.265	0.088	11.3
TERI	Terreton, ID	INL	43.84168	-112.41825	1460.6	15	150	0.287	0.163	10.9
TFGI	Filer (Fairgrounds), ID	PN	42.56878	-114.60155	1147.0	3	150	0.267	0.094	11.2
TRMU	Tremonton, UT	UCC	41.72293	-112.15375	1320.1	3	150	0.315	0.159	11.6
TRTI	Terraton, ID	PN	43.87040	-112.26394	1478.0	3	150	0.184	0.079	7.6
TWFI	Twin Falls (Kimberly), ID	PN	42.54611	-114.34527	1194.8	3	150	0.250	0.100	8.0
STNI1	Stanley RS, ID	RAWS	44.16917	-114.92528	1916.0	6.1	150	0.241	0.115	9.1
CHRI1	Challis ID	RAWS	44.50448	-114.22249	1592.9	6.1	150	0.245	0.110	10.7
SMYI1	Salmon, ID	RAWS	45.14983	-113.94536	1554.5	6.1	150	0.338	0.161	12.2
LDOI1	Leadore Creek, ID	RAWS	44.70192	-113.34692	1874.5	6.1	150	0.217	0.086	8.9
PVLN2	Paradise Valley, NV	HADS	41.18556	-117.66028	1339.0	3	150	0.219	0.088	8.4
NCLV	Clover Valley, NV	DRI	40.86833	-114.96944	1720.6	3	150	0.227	0.111	9.8
PVLU1	Park Valley, UT	SCAN	41.77374	-113.26350	1554.5	3	150	0.244	0.099	10.4
FSLM8	Fishtail, MT	RAWS	45.45806	-109.57139	1386.8	6.1	150	0.312	0.170	11.7
SCFI1	Slate Creek, ID	RAWS	45.63333	-116.28333	477.9	6.1	150	0.162	0.053	8.4

The RAWS and SCAN stations included in the development of ET_r, K_e, and dormant K_c surfaces do report the daily dewpoint temperature information. However the reported dewpoint was ignored when determining ET_r and a K_o from ETIdaho was used instead, with reported minimum air temperature, to compensate for the aridity of these stations. This process is described in the next section.

Downloading AWS Meterological Data

The initial coding of the scripts to download and process meterological data from the various stations assumed that the data streams would have very short interuptions due to operational issues -- with missing periods presumably shorter than 5 days. To handle that possibility the scripts were coded to refresh the prior downloads only for the prior ten day period and if data were missing then the script used the last known data to fill in prior to interpolation. This did not apply well however, do to extended periods of missing data and resulted in ET_r surfaces having values that were biased low and high. For example one station datastream was off line for and extended period of time longer than 30 days.

The scripts and procedures for interpolating the daily ET_r have been improved to only allow filling of missing data for periods of two (days) or shorter and refreshing the local AWS data store by downloading the last 45 days of record. These scripts for downloading meteorological data were run on a daily frequency. The scripts required modification to handle the *new* Agrimet API for the Pacific Northwest Region that occurred during the project.

Daily ET_r and K_e Surfaces.

Each morning a script after the meteorological dataset was updated, a script was run to compute the following in addition to other items:

- Reference Evapotranspiration (ET_r): ASCE/EWRI Standardized Penman Monteith Equation for the alfalfa reference. For the provisional processing period, the vapor pressure deficit was based on average reported dew point temperatures for stations considered to be in agricultural settings (Agrimet, AgNet, NiceNET). For stations considered to be non agricultural settings, the dew point temperature was adjusted based on the minimum air temperature and the ET_{Idaho} dew point depression (k_o) table.

- Soil surface evaporation and K_e: Methods outlined in METRIC spreadsheet, ET_{Idaho}, and FAO. The precipitation is split into morning and afternoon components and the soil surface evaporation is computed in between. The script assumes a fully wet soil surface on January 1. The thickness of the surface layer, skin, was assumed to be 150 mm. ETIdaho typically used 100 mm; however, some of the METRIC worksheets for prior applications used 150 mm.

The daily ET_rF and K_e surfaces were interpolated from set of AWS stations listed in Table 9 and shown in Figure 29 (14 stations are located outside the figures' extent) and further described in the next section, The spatial interpolation was done using a weighted spline (1/3) and natural neighbor interpolation (2/3) processes included in ArcGIS.

Meteorologic Data Assessment

The 66 automated weather stations used for generation of daily ET_r and K_e are from Agrimet (PN and GP), RAWS, INL/NOAA, NiceNET/DRI, and AgWxNET/UCC meteorological networks. Each network has typically a different objective. The Pacific Northwest Agrimet (PN) network is focused on weather conditions in an agricultural setting. The USBR/USFS remote automatic weather station (RAWS) is focused on weather conditions to support federal land management agency's projects, primarily wildland fire. The locations of the various AWS sites are shown in Figure 29.

For the near real time production of daily ET_r the meteorological data streams were not assessed for quality. Only the wind speed and dew point temperatures were considered. For wind speed, the station's report anemometer height was considered and wind speeds were translated to 2 meter heights based on the logarithmic wind speed profile function, Allen et al. 2005. The dew point for RAWS stations was filtered for average K_o (Tmin – Tdew) conditions against average monthly K_o values used in ETIdaho.

The weather data assessment documented in this appendix considers the entire 2016 period of record (January through November), looking at trends and differences between stations. Air temperatures (maximum and minimum) were visually evaluated for spikes and against close by stations. The dew point temperature was evaluated visually against minimum air temperature and K_o trends and the number of days exceeding thresholds for the April through September periods. Precipitation was included in the evaluation because it impacts K_o and soil evaporation. Solar radiation was compared to theoretical clear sky radiation (R_{so}), water vapor adjusted clear sky radiation (R_{so*}) and minimum threshold of 10% of extraterrestrial solar radiation (R_a). In addition, the solar radiation was compare to other close by stations. Wind speed was evaluated for discontinuities and daily variation.

For each station the time series of temperature (minimum, maximum and dew point), K_o, precipitation, solar radiation, and wind speed were plotted. These are shown in Figure 30 through Figure 95. The ratio of R_s/R_{so} for "clear" days was evaluated using Ref-ET and QAQC programs developed by Allen and Li (2016). The sixty day and seasonal average ratios for each station are shown in Table 10 along with period of record ET_r (% of average), number of days exceeding K_o thresholds of 5, 10, 15, and 20 degrees C for April through September and number of missing days. Figure 29 show the average "clear day" solar radiation ratio (R_s/R_{so}) for the various stations.

The initial coding of the ET_r scripts for processing the meteorological considered agricultural weather stations to be sited where aridity effects would not be seen in the dew point temperature. To handle arid station location dew point temperature, the average daily dewpoint temperature depression from minimum daily air temperature, K_o (Tmin – Tdew) was evaluated against the standard average monthly K_o used in ETIdaho. This assumption to use typically Ko of 1.5C may not be valid for the 2016 season. And, various non RAWS AWS were assumed not to need dew point temperature adjustments which appears to be in-valid.

After reviewing all the meteorological data series, a decision was made to adjust solar radiation for all stations based on "clear-day" solar radiation expectations. Furthermore; after evaluating the dew point depressions from minimum air temperature at all the stations and between stations, a decision was made to adjust the dew point for all stations when the depression exceeded 5 degrees plus the standard expected depression from ETIdaho (1.5 degrees for the months April through September). Thus when the reported dew point depression was greater than 6.5 (5.0 + 1.5) degrees, the dew point temperature was adjusted to be 6.5 degrees below the minimum air temperature. The stations highlighted in Table 10 were dropped from the final set due to perceived issues with the station.

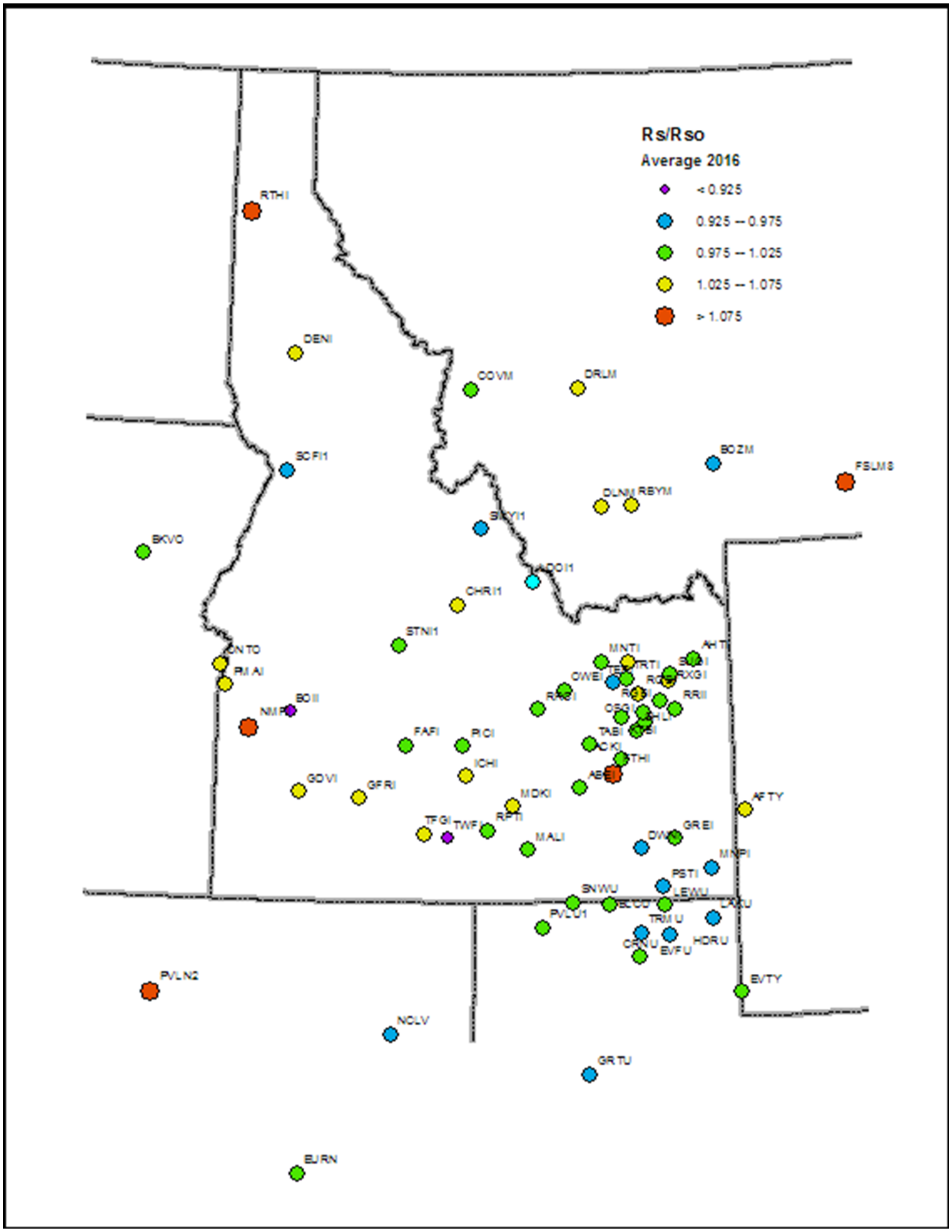


Figure 29. AWS Stations used for 2016 near real time METRIC application. The stations are depicted with their seasonal Rs/Rso ratios for clear days.

Table 10. AWS Locations for 2016 Near Real Time METRIC ET_r. Data quality review summary.

		Missing	Jan - Nov ET_r		R_s/R_{so}	Days with K_o exceeding (Apr-Sep)			
Station	**Network**	**Days**	**(mm)**	**%**	**Ratio**	**>5C**	**>10C**	**>15C**	**>20C**
ABEI	PN/INL	None	1531	105%	0.99	32	2	0	0
ACKI	INL	None	1504	103%	1.00	71	14	3	0
AFTY	PN	*	1312	90%	1.05	37	0	0	0
AHTI	PN	None	1301	89%	1.02	20	2	0	0
BKVO	PN	None	1256	86%	1.00	6	0	0	0
BLCU	UCC	None	1504	103%	0.98	102	77	44	12
BOII	PN	None	910	63%	0.91	26	1	0	0
BOZM	GP	None	1470	101%	0.97	99	21	2	0
CHRI1	RAWS	None	1097	75%	1.03	141	70	16	1
COVM	PN	None	1022	70%	1.00	11	0	0	0
CRNU	UCC	None	1495	103%	1.00	55	4	0	0
DENI	PN	None	1150	79%	1.06	29	3	0	0
DLNM	GP	None	1291	89%	1.05	16	1	0	0
DRLM	PN		1397	96%	1.03	14	1	0	0
DWNI	PN	None	1449	100%	0.97	55	7	0	0
EURN	PN	None	1642	113%	0.99	36	3	0	0
EVFU	UCC	3	1215	83%	0.97	42	4	0	0
EVTY	PN	None	1534	105%	0.98	21	0	0	0
FAFI	PN	None	1418	97%	1.01	31	5	0	0
FSLM8	RAWS	None	1488	102%	1.10	84	24	3	0
FTHI	PN	None	1621	111%	1.10	18	0	0	0
GDVI	PN	None	1729	119%	1.03	48	9	0	0
GFRI	PN	None	1953	134%	1.04	103	32	5	0
GREI	PN	None	1590	109%	0.99	62	15	2	0
GRTU	PN	None	2009	138%	0.97	86	29	7	0
HAMI	INL	None	1672	115%	1.03	79	6	0	0
ICHI	INL	None	1685	116%	1.06	40	0	0	0
IFAI	INL	None	1400	96%	1.00	78	16	2	0
KTBI	PN/INL	None	1647	113%	1.00	103	40	11	2
LAKU	UCC	None	1354	93%	0.97	15	1	0	0
LDOI1	RAWS	None	1355	93%	1.02	83	15	3	0
LEWU	UCC	None	1232	85%	1.01	1	0	0	0
MALI	PN	None	1571	108%	1.01	36	7	4	1
MDKI	INL	None	1578	108%	1.03	25	0	0	0
MNPI	PN	None	1194	82%	0.95	4	0	0	0
MNTI	PN/INL	None	1419	98%	1.00	24	0	0	0
NCLV	DRI	3	1544	106%	0.97	53	10	2	0
NMPI	PN	None	1621	111%	1.08	52	5	0	0
ONTO	PN	None	1670	115%	1.04	110	34	3	1
OSGI	PN	*	1377	95%	0.99	9	0	0	0
OWEI	INL	None	1633	112%	0.99	81	12	2	0
PICI	PN	None	1370	94%	1.02	73	14	1	0
PMAI	PN	None	1527	105%	1.03	54	2	0	0
PSTI	PN	None	1305	90%	0.97	22	1	0	0
PVLN2	DRI	None	1897	130%	1.13	115	67	24	3
PVLU1	SCAN	*	1377	95%	1.01	120	88	41	10
RBYM	GP	None	1427	98%	1.04	85	22	3	0
RGBI	PN	None	1609	111%	0.98	68	14	1	0
ROBI	INL	27	1245	86%	1.03	17	1	0	0
RPTI	PN	*	1668	115%	0.98	28	2	0	0
RRCI	INL	26	1320	91%	1.00	72	13	0	0
RRII	PN	*	1827	126%	1.01	101	30	5	0
RTHI	PN	13, 14	1060	73%	1.09	4	0	0	0
RXGI	PN	None	1438	99%	1.04	18	3	1	0
SCFI1	RAWS	None	1195	82%	0.93	60	8	0	0
SHLI	PN	None	1386	95%	1.01	28	3	0	0
SMYI1	RAWS	None	1139	78%	0.96	133	68	22	4

		Missing	Jan - Nov ET_r		R_s/R_{so}	Days with K_o exceeding (Apr-Sep)			
Station	Network	Days	(mm)	%	Ratio	>5C	>10C	>15C	>20C
SNWU	UCC	None	1606	110%	0.98	52	9	1	0
STNI1	RAWS	None	1089	75%	0.99	21	2	0	0
SUGI	INL	None	1500	103%	1.00	39	3	0	0
TABI	INL	None	1652	114%	1.01	50	8	0	0
TERI	INL	None	1373	94%	0.97	39	2	0	0
TFGI	PN	*	1578	108%	1.05	112	26	2	0
TRMU	UCC	None	1633	112%	0.97	85	26	1	0
TRTI	PN	None	1486	102%	1.00	34	3	0	0
TWFI	PN	None	1505	103%	0.90	52	3	0	0

Aberdeen, ID (ABEI)

The ABEI station is a joint station between PN-Agriment and INL. The anemometer is mounted at 2 m above ground surface. This station is assumed to be in an agricultural setting with no aridity effects. Thus the estimated dew point temperature is taken as the reported average daily dew point temperature. The data time series for the various parameters are shown in Figure 30. Within 35 km of ABEI, one other AWS station is available for comparison: FTHI (Figure 50). The daily temperatures are consistent between stations; however, there appears to be a "spike" for minimum air temperature at ABEI on March 26 of -15.5C which is not supported by the FTHI station. Because this is outside the growing season, it will be ignored. The dew point depression from minimum air temperature, K_o, pattern is similar to that of FTHI except that it appears to be slightly greater. Only 32 days exhibited depressions greater than 5C compared to 18 days for FTHI for the period between April 1st and September 30th. The solar radiation, R_s, appears to be fine when compared to R_{so} and R_{so*}. Wind speeds are appropriated and visually comparable to those of FHTI. The precipitation pattern and amounts are similar between ABEI and FTHI. The January through November cumulative ETr based on the non-quality controlled data was 1531 mm for ABEI which is 105% of the average cumulative for all AWS station prior to adjustments.

Adjustments: The solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5C which impacted 17 days during the period from April 1st to September 30th. The air temperatures for March 26th were adjusted to be the average of the prior and next days.

Blackfoot, ID (ACKI)

The ACKI station is an INL/NOAA station which PN-Agrimet has incorporated into their system. The anemometer height is 15 m above ground surface and in situated in an urban setting. Figure 31 shows the time series of the daily weather data for this station. This station has three other AWS stations within 35 km: FTHI (Figure 50), SHLI (Figure 85), and TABI (Figure 90). The FTHI station is the closest at 15 km. The air temperatures, solar radiation, and wind speeds look good and compare favorably with the other stations. However, based on the SHLI and TABI solar records, there might have been a calibration adjustment at the end of June which is not necessarily supported by R_s/R_{so} ratios. At this station, it was assumed that the setting was similar to that of an agricultural setting and no adjustments were made in the real time mode. However, examine of K_o over time and with the other 3 stations suggest that it might deserve treatment as a station in an arid setting. This station had 71 days with K_o values greater than 5C and 14 days greater than 10C, three of which were greater 15C. The FTHI station only had 18 days with K_o greather than 5C. Using the non-quality controlled data, the cumulative ET_r for January through November is 1504 mm which is 103% of the average for all AWS stations.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 48 days during the period from April 1st through September 30th.

Afton, WY (AFTY)

The AFTY station is a Pacific Northwest Agrimet station and a historical ETIdaho station. This station is assumed to be sited in an agricultural setting. The station is located outside the study area and is included as an anchor station for interpolation of surfaces for the entire study area. The meteorological time series for this station is shown in Figure 32. The station has no other AWS stations within 35 km. With the exception of maximum air temperature, the temperatures have appropriate response. However, the maximum air temperature during the spring appears to be faulty with several spikes greater than summer time temperatures. Because minimum and maximum air temperature are from a single sensor; these unexpected high maximums also call into question the minimum air temperature. Additionally, this sensor behavior may be reflected in the dew point temperature for that period. Solar radiation appears to have a shift in calibration around middle of July. For the July through November period R_s/R_{so*}ratio for "clear days" was 1.07 to 1.09 as estimated by the QAQC program by Allen and Li. Wind speeds at Afton are significantly lower than other stations; however, this may be due in part by the topography of the valley where the station is located. The maximum air temperature reported at the airport (KAFO unofficial) for April 21st was 20.5C compared to 46.0C from this Agrimet station. For May 1st, the maximum temperature reported for the airport was 12.8C compared to 14.8C from the Agrimet station. The cumulative ET_r for January through November associated with the uncorrected data is 1312 mm or 90% of the average for all stations.

Adjustments: Air temperature for the period of January through April based on solar radiation data (coefficients determined from the May through June period) and minimum air temperature even though it is suspect. The January through April air temperatures and dew point were taken from the Afton airport based on regression of the May through October period. The dew point temperature depression was limited to 6.5C. This impacted 20 days during the period from April 1st through September 30th. Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios.

Ashton, ID (AHTI)

The AHTI station is a Pacific Northwest Agrimet network station. This station is assumed to be located in an agricultural setting with an anemometer height of 3 m. The meteorological time series for the station are shown in Figure 33. This station has two other AWS stations located within 35 km; RXGI and SUGI (Figure 83 and Figure 89). The air temperature time series appear to be appropriate and compares well with the nearby stations. The dew point and K_o exhibit the behavior for stations located in an agricultural setting. Only 20 days during April through September are greater than 5C. During the near real processing for this station, no adjustment was made for dew point. The solar radiation compares favorably for R_s/R_{so} and to that measured at the SUGI site. The wind speed record does not appear to have any issues. The period of record ET_r is 1301 mm (89% of AWS average) prior to adjustments.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 11 days during the period from April 1st through September 30th.

Baker Valley, OR (BKVO)

The BKVO station is a Pacific Northwest Agrimet station with a 3m anemometer height. This station located outside the study area provides control for interpolated surfaces along the edge of the study area (an anchor station). The meteorological data series for the station are shown in Figure 34. The data series for all the parameters look good and there no issues. The K_o time series indicates that the station is probably representative of an agricultural setting with only 6 days exceeding 5C during the April through September period. The solar radiation data shows good agreement with expected values. There are no stations within 35km to compare this station to. The period of record ET_r for BKVO was 1256 mm (86% of AWS average) prior to adjustments.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature did not exceed 6C.

Blue Creek, UT (BLCU)

The BLCU station is a UCC AgWxMet station. The data for this station was downloaded from the PN Agrimet system that maintains a record of the station data. It is assumed that the anemometer height is 3 meters and that because the station was in an agricultural network it would not be considered an arid station. The time series data for this station is shown in Figure 35. There is another AWS station within 35 km of this station: SNWU (Figure 87). The minimum and maximum air temperatures do not have noticeable "spikes" and is similar to those at SNWU. The reported average dew point temperature and K_o appears to be more representative of an arid location than that of an irrigated location with K_o values exceeding 5C for 102 days during the period April through September and 44 days exceeded 15C. This is especially true when compared to the SNWU station where K_o exceeded 15C for only one day during the same period. The solar radiation seems to be low from May through August when compared to R_s/R_{so} ratios and to the solar radiation reported at the SNWU. The wind speeds are relative low compared to "standard" Agrimet stations operated by the USBR Pacific Northwest region. However, the wind speeds at the SNWU station are similar with more day to day variation. The unadjusted data series for this station results in a January to November cumulative ET_r of 1504 mm (103% of average) which is lower than 1606 mm for SWNU station.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 98 days during the period from April 1st through September 30th (more than 50%).

Boise, ID (BOII)

The BOII station is a PN Agrimet network station located in an urban setting. This station has neighboring AWS stations within 35 km of its location. The temperature time series data (Figure 36) does not exhibit any "spikes" or anomalies. The dew point depression, K_o, shows slight aridity effects; but is consisted throughout the period. The solar radiation appears to be under measured when compared to "clear day" R_s/R_{so} ratios at this location (90%); however, it may be due to the station's location which is evident in the wind speed record. The average daily wind speed never exceeds 2 m/s. This station is located outside of the study area and was only included to assist in creating interpolated ET_r surfaces for the study area. For the January to November period the cumulative ETr was 910 mm (63% of all AWS) and was the lowest in the data set (Table 10).

Adjustments: If the station is to remain in the group of stations to provide interpolated surfaces, the solar radiation should be adjusted by R_s/R_{so*} ratio for clear days. Without any adjustments the meteorological results in a Jan-Nov ETr of 910 mm, 63% of the average Jan-Nov ETr for all AWS stations. It is recommended that this station, BOII, be dropped out of the AWS set for the final product. This station will not be used in the final due to the issues with wind speed and other stations can provide the anchoring for the daily images.

Bozeman, MT (BOZM)

The BOZM station is a GP Agrimet network station. The anemometer height was assumed to be 2 meters. The station is located outside the study and is included in the AWS station set to provide anchoring of interpolation images for the entire study area. There are no neighboring stations with in 35 km of its location. The meteorological time series are shown in Figure 37. The minimum and maximum temperature series exhibit no anomalies. The average daily dew point temperature and depression from minimum is more representative of a non-irrigated/arid setting with K_o exceeding 5C for 99 days for the April through September period of which 22 days exceeded 10C. The solar radiation appears to be fine when compared to the "clear day" R_s/R_{so} ratios. The "clear day" ratios are between 95 and 99%. The wind speed series shows no anomalies. This station had issues starting Nov 28th and appears that it was undergoing maintenance. The cumulative January through November ET_r for this station was 1470 mm (101% of average for all stations).

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 66 days during the period from April 1st through September 30th.

Challis, ID (CHRI1)

The CHRI1 station is a RAWS network station. This station is located in the study area (Path 40 Row 29). The wind anemometer height is assumed to be 6.1-meter based on standard RAWS station configurations. For near real time processing, the station was assumed to be arid. Figure 38 shows the meteorological data time series associated with the station. For calculation of ET_r the reported average daily dew point temperature and minimum air temperature was evaluated for the prior 5 day period. If the average 5 day depression (K_o = Tmin – Tdew) exceeded the ETIdaho recommended K_o (1.5 for the summer months) then the estimated dew point temperature was computed as Tmin – ETIdaho(K_o). When compared to other southern Idaho Agrimet station for 2016, this adjustment may be too strong. Some of the non PN-Agrimet network stations thought to be in agricultural settings (NiceNet, AgWxNet, GP-Agrimet) exhibit similar dew point depressions as this station. The solar radiation series looks good when compared to "clear day" R_s/R_{so} ratios. The wind speed at 2 m series appears to be low; however, there is day to day variation. This low wind speed may be in part due to landscape effects surrounding the station at 6.1 meters. The cumulative January through November ET_r for this station was 1097 mm (75% of AWS average).

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 122 days during the period from April 1st through September 30th (two thirds of the days).

Corvallis, MT (COVM)

The COVM station is a PN-Agrimet network station and is treated as being in an agricultural setting with a 3-meter anemometer height. The station is located outside the study and is included in the AWS station set to provide anchoring of interpolation images for the entire study area. The station has no neighboring stations within 35 km. The meteorological time series for this station are shown in Figure 39. The air temperature, dew point, precipitation, solar radiation exhibits no anomalies. The wind speed series shows low wind speeds typically below 2 m/s with day to day variation. These are similar to those at Dworshak (DENI); however, at Deer Lodge the (DRLM) winds are typically above 2 m/s. The cumulative January through November ET_r for this station was 1022 mm (70% of AWS average).

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 4 days during the period from April 1st through September 30th.

Corinne UT (CRNU)

The CRNU station is part of the AgWxNet/UCC network and has been assimilated in to the PN-Agrimet data archival and reporting system. The anemometer height has been assumed to be 3-meters. The meteorological time series for this station are shown in Figure 40. The station has two neighboring stations within 35 km: EVFU and TRMU (Figure 29 and Figure 93). The temperature time series has no anomalies and compares well with those at EVFU and TRMU. The dew point depression for this station between those at TRMU and EVFU. During the summer months it is between 2 and 12C. The solar radiation series compares well to the other stations and "clear day" solar radiation compares well with R_s/R_{so} ratios. The wind speed series compares well with those of TRMU 28 km away. The cumulative January through November ET_r for this station was 1495 mm (75% of AWS average).

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 35 days during the period from April 1st through September 30th.

Dworshak, ID (DENI)

The DENI station is part of the PN-Agrimet network and a historical ETIdaho station. The station is outside of the study area and is only included for the interpolation of surfaces. The anemometer height has been assumed to be 3-meters. The meteorological time series for the station are shown in Figure 41. The station has no neighboring stations within 35 km. The temperature series do not exhibit any anomalies. The dew point depression for the station are consisted with other historical AWS ETIdaho stations. The solar radiation series is consisted with clear day R_s/R_{so} ratios except for the last half of the 2016 season where the clear R_s/R_{so} ratios are above 1.10. The daily wind speeds are typical for sites where topography shield the anemometer such as SCFI1 and COVM. The cumulative January through November ET_r for this station was 1179 mm (79% of AWS average).

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 14 days during the period from April 1st through September 30th.

Dillon, MT (DLNM)

The DLNM station is a GP Agrimet network station. The anemometer height was assumed to be 2 meters. The station is located in the northern portion of the study area. The RBYM station is located within 35 km of this station. The meteorological time series are shown in Figure 42. The minimum and maximum temperature series exhibit no anomalies. The average daily dew point temperature and depression from minimum appears to be representative of an irrigated area and is typically smaller than that at RBYM. The solar radiation appears to be fine when compared to the "clear day" R_s/R_{so} ratios. The general temporal trends and events are similar to those at RBYM with the exception of dew point depression, RBYM appears to be less humid. The cumulative January through November ET_r for this station was 1291 mm (89% of average for all stations).

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 9 days during the period from April 1st through September 30th.

Deer Lodge, MT (DRLM)

The DRLM station is a PN Agrimet network station and has an anemometer height of 3-meters. The station is located outside the study area and is included in the AWS station set to provide anchoring of interpolation images for the entire study area. This station has no neighboring AWS stations within 35 km. The meteorological time series for this station are shown in Figure 43. The minimum and maximum air temperature series exhibit no anomalies. The average dew point temperature and depression from minimum appears to be representative of an irrigated area The solar radiation appears to be fine when compared to the "clear day" R_s/R_{so} ratios. The daily average wind speeds are typically above 2 m/s and no issues are apparent. The cumulative January through November ET_r for this station was 1397 mm prior to adjustments (96% of average for all stations).

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which only impacted 5 days during the period from April 1st through September 30th.

Downey, ID (DWNI)

The DWNI station is a PN Agrimet network station and has an anemometer height of 3-meters. This station has one neighboring AWS station within 35 km, GREI. The meteorological time series for this station are shown in Figure 44 and exhibit similar trends and patterns as those at GREI (Figure 53). The minimum and maximum air temperature series exhibit no anomalies. The average dew point temperature and depression from minimum appears to be representative of a slightly arid irrigated area during the July through September period. The solar radiation appears to be slightly low when compared to the "clear day" R_s/R_{so} ratios. The daily average wind speeds are typically above 2 m/s and no issues are apparent even though they are lower than those at GREI. The cumulative January through November ET_r for this station was 1449 mm prior to adjustments (100% of average for all stations).

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 35 days during the period from April 1st through September 30th.

Eureka, NV (EURN)

The EURN station is a PN Agrimet network station and has an anemometer height of 3-meters. The station is located outside the study area and is included in the AWS station set to provide anchoring of interpolation images for the entire study area. This station has no neighboring AWS stations within 35 km. The meteorological time series for this station are shown in Figure 45. The minimum and maximum air temperature series exhibit no anomalies with the exception of the beginning of the year. The average dew point temperature and depression from minimum appears to be representative of a slightly arid irrigated area The solar radiation appears to be fine when compared to the "clear day" R_s/R_{so} ratios. The daily average wind speeds appear to have no issues. The cumulative January through November ET_r for this station was 1642 mm prior to adjustments (113% of average for all stations).

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 19 days during the period from April 1st through September 30th.

Evan's Farm, UT (EVFU)

The EVFU station is part of the AgWxNet/UCC network and has been assimilated in to the PN-Agrimet data archival and reporting system. The station is located outside the study and is included in the AWS station set to provide anchoring of interpolation images for the entire study area. The anemometer height has been assumed to be 3-meters. The meteorological time series for this station are shown in Figure 46. The station has three neighboring stations within 35 km: CRNU, LEWU and TRMU (Figure 40, Figure 61 and Figure 93). The station has missing data for the period between May 13th and the 20th. The temperature time series compares well with those at CRNU, LEWU and TRMU. The dew point depression for this station compares well with those at CRNU and TRMU. The wind speeds are closer to those at LEWU and lower than those at CRNU and TRMU. The solar radiation appears to be low when compared to the "clear day" R_s/R_{so} ratios. The cumulative January through November ET_r for this station was 1215 mm prior to adjustments (83% of average for all stations) and is lower than CRNU, LEWU, and TRMU of 1495, 1232, and 1633 mm respectively.

Adjustments: Because of the missing data period and its proximity to three other AWS stations, this station will not be used in the final product. If it was to be used, solar radiation should be adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature should limited to 6.5 C which would impacted 20 days during the period from April 1st through September 30th. The missing data for this station should be based on CRNU for air temperature, dew point, solar radiation and precipitation. The wind speeds should be used from LEWU

Evanston, WY (EVTY)

The EVTY station is part of the PN-Agrimet network. The station is outside of the study area and is only included for the interpolation of surfaces. The anemometer height has been assumed to be 3-meters. The meteorological time series for the station are shown in Figure 47. The station has no neighboring stations within 35 km. The temperature series do not exhibit any anomalies. The dew point depressions for the station are consisted with other AWS stations identified as being in an irrigated area. The solar radiation series is consisted with clear day R_s/R_{so} ratios. The daily wind speed series exhibit no visual anomalies. The precipitation series shows a precipitation event on Nov 3 (67.6mm) is not support by close by stations not included in the AWS station set. The PN Agrimet personnel have indicated that the event was probably associated with station maintenance. The cumulative January through November ET_r for this station was 1534 mm (105% of AWS stations average).

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 7 days during the period from April 1st through September 30th. The precipitation for November 3rd was set to zero.

Fairfield, ID (FAFI)

The FAFI station is a Pacific Northwest Agrimet network station and is a historical ETIdaho station. This station is assumed to be located in an agricultural setting with an anemometer height of 3 meters. The meteorological time series for the station are shown in Figure 48. This station has no neighboring AWS stations located within 35 km. The air temperature time series appear to be appropriate with no anomalies. The dew point and depression exhibit the behavior for stations located in an agricultural setting. Only 31 days during April through September are greater than 5C. The solar radiation compares favorably for R_s/R_{so} with the exception of the June through July period which appears to be low. This is possibly due to smoke inversions from wildland fires upwind. The wind speed record does not appear to have any issues. The period of record, January through November, ET_r is 1418 mm (97% of AWS average) prior to adjustments.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios even for the June and July period. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 14 days during the period from April 1st through September 30th.

Fishtail, MT (FSLM8)

The FSLM8 station is a RAWS network station. This station is outside the study area and is included in the AWS station set to provide anchoring of interpolation images for the entire study area. There are no neighboring stations with in 35 km of its location. The wind anemometer height is assumed to be 6.1-meter based on standard RAWS station configurations. The air temperature, solar radiation, precipitation and wind speed series show no anomalies as shown in Figure 49. For near real time processing, the station was assumed to be arid and the ETIdaho K_o was applied in the fashion described for CHRI1. The solar radiation appears to be high when compared to "clear day" R_s/R_{so} ratios. The cumulative January through November ET_r for this station was 1488 mm (102% of AWS average).

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 66 days during the period from April 1st through September 30th.

Fort Hall, ID (FTHI)

The FTHI station is a Pacific Northwest Agrimet network station and is a historical ETIdaho station. This station is assumed to be located in an agricultural setting with an anemometer height of 3 meters. The meteorological time series for the station are shown in Figure 50. This station has three neighboring AWS stations located within 35 km: ABEI, ACKI, and TABI (Figure 30, Figure 31, and Figure 90). The air temperature time series appear to be appropriate with no anomalies and compares favorably with the other stations. The dew point and depression exhibit the behavior for stations located in an agricultural setting and appears to be lower than the other stations. Only 18 days during April through September are greater than 5C. The solar radiation appears to be to high when compared to "clear sky" R_s/R_{so} ratios. The wind speed record does not appear to have any issues. The period of record, January through November, ET_r is 1621 mm (111% of AWS average) prior to adjustments. This compares to 1531, 1504, and 1652 mm for ABEI, ACKI, and TABI respectively.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios even for the June and July period. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 8 days during the period from April 1st through September 30th.

Grandview, ID (GDVI)

The GDVI station is part of the PN-Agrimet network and a historical ETIdaho station. The station is outside of the study area and is only included for the interpolation of surfaces. The anemometer height has been assumed to be 3-meters. The meteorological time series for the station are shown in Figure 51. The station has no neighboring stations within 35 km. The temperature series do not exhibit any anomalies. The dew point depression for the station are consisted with other historical AWS ETIdaho stations located near desert areas. The solar radiation series is consisted with "clear sky" R_s/R_{so} ratios; however, the values appear to be high. The daily wind speeds exhibit no anomalies. The cumulative January through November ET_r for this station was 1729 mm (119% of AWS average).

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 33 days during the period from April 1st through September 30th.

Glenns Ferry, ID (GFRI)

The GFRI station is part of the PN-Agrimet network and a historical ETIdaho station. The station is located just inside of the study area. The anemometer height has been assumed to be 3-meters. The meteorological time series for the station are shown in Figure 52. The station has no neighboring stations within 35 km. The temperature series do not exhibit any anomalies. The dew point depression for the station are higher than expected throughout the summer (May through September) based on the consistent 1 mm precipitation events during the same period. The solar radiation series is consisted with "clear sky" R_s/R_{so} ratios; however, the values appear to be high. The daily wind speeds exhibit no anomalies. The cumulative January through November ET_r for this station was 1953 mm (134% of AWS average) the second highest based on the non-adjusted meteorological data.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 87 days during the period from April 1st through September 30th.

Grace, ID (GREI)

The GREI station is a Pacific Northwest Agrimet network station. This station is assumed to be located in an agricultural setting with an anemometer height of 3 meters. The meteorological time series for the station are shown in Figure 53. This station has one neighboring AWS station located within 35 km: DWNI (Figure 44). The air temperature time series appear to be appropriate with no anomalies and compares favorably with DWNI. The dew point and depression exhibit the behavior for stations located in a drier agricultural setting and appears to be typically higher than DWNI. During April through September period; 62 days exhibit dew point depressions greater than 5C. The solar radiation appears to correct when compared to "clear sky" R_s/R_{so} ratios. The wind speed record does not appear to have any issues. The period of record, January through November, ET_r is 1590 mm (109% of AWS average) prior to adjustments. This compares to 1449 mm for DWNI.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios even for the June and July period. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 47 days during the period from April 1st through September 30th.

Grantsville, UT (GRTU)

The GRTU station is a PN-Agrimet network station and is treated as being in an agricultural setting with a 3-meter anemometer height. The station is located outside the study and is included in the AWS station set to provide anchoring of interpolation images for the entire study area. The station has no neighboring stations within 35 km. The meteorological time series for this station are shown in Figure 54. The air temperature, dew point, precipitation, solar radiation, and wind speed series exhibit no anomalies. The dew point depression from minimum air temperature is higher than that expected for a station located within irrigated agriculture. The solar radiation appears to correct when compared to “clear sky” R_s/R_{so} ratios. The cumulative January through November ET_r for this station was 2009 mm (138% of AWS average) the highest of all stations based on non-adjusted data.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 69 days during the period from April 1st through September 30th.

Hamer, ID (HAMI)

The HAMI station is a INL/NOAA station which PN-Agrimet has incorporated into their system. The anemometer height is 15 m above ground surface. The meteorological time series for this station are shown in Figure 55Figure 55. The station has four neighboring stations within 35 km: MNTI, ROBI, TERI and TRTI (Figure 65, Figure 78, Figure 91 and Figure 94). The air temperature, dew point, solar radiation, and wind speed series exhibit no anomalies and compare favorably with the neighboring stations. The dew point depression from minimum air temperature is higher than that expected for a station located within irrigated agriculture. The solar radiation appears to correct when compared to “clear sky” R_s/R_{so} ratios. The precipitation record shows two extreme values above 20 mm/day: 45.7 mm/day on May 15th and 41.4 mm/day on July 30th. These precipitation events are not supported by the records at the neighboring stations. The cumulative January through November ET_r for this station was 1672 mm (115% of AWS average) based on non-adjusted data.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 69 days during the period from April 1st through September 30th. The two extreme precipitation values (May 15th and July 30th) were set to zero based on the neighboring station precipitation records.

Richfield, ID (ICHI)

The ICHI station is a INL/NOAA station which PN-Agrimet has incorporated into their system. The anemometer height is 15 m above ground surface. The meteorological time series for this station are shown in Figure 56. The station has one neighboring stations within 35 km: PICI (Figure 71). The air temperature, dew point, solar radiation, and precipitation series exhibit no anomalies and compare favorably with the neighboring station. The dew point depression from minimum air temperature is lower typically than PICI and is similar to what would be expected for a station located within irrigated agriculture. The solar radiation appears to high when compared to “clear sky” R_s/R_{so} ratios. The wind speed is higher than that for PICI and is to be expected based on location of the two stations. The cumulative January through November ET_r for this station was 1685 mm (116% of AWS average) based on non-adjusted data and is approximately 300 mm higher than PICI.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 17 days during the period from April 1st through September 30th.

Idaho Falls, ID (IFAI)

The IFAI station is a INL/NOAA station which PN-Agrimet has incorporated into their system. The anemometer height is 15 m above ground surface. The meteorological time series for this station are shown in Figure 57. The station has six neighboring AWS stations within 35 km: KTBI, OSGI, RGBI, ROBI, RRII and SHLI (Figure 58, Figure 69, Figure 77, Figure 78, Figure 81 and Figure 85). The OSGI and SHLI stations are the closest at less than 11 km. The air temperature, dew point, solar radiation, and precipitation series exhibit no anomalies and compare favorably with the neighboring station. The dew point depression from minimum air temperature is more typical of more arid agriculture setting. The solar radiation appears ok when compared to “clear sky” R_s/R_{so} ratios. The wind speed at this station appears to be consistently lower than the other stations. The precipitation of 25 mm/day on September 23rd is supported by the precipitation records associated with the neighboring stations. The cumulative January through November ET_r for this station was 1400 mm (96% of AWS average) based on non-adjusted data. This compares to 1647, 1377, 1609, 1827 and 1386 mm for KTBI, OSGI, RGBI, RRII and SHLI respectively.

Adjustments: Due to this stations proximity to two other stations with good data, this station has been dropped from the final set. If this station was to be kept the solar radiation should be adjusted based on observed clear day

R_s/R_{so} ratios. And, the dew point depression from minimum air temperature should be limited to 6.5 C which would impacted 50 days during the period from April 1st through September 30th.

Kettle Butte, ID (KTBI)

The KTBI station is a joint station between PN-Agrimet and INL and is a historical ETIdaho station. The anemometer is mounted at 2 m above ground surface. The data time series for the various parameters are shown in Figure 58. Within 35 km of ABEI, four other AWS station are available for comparison: IFAI, OSGI, ROBI, SHLI and TERI (Figure 57, Figure 69, Figure 78, Figure 85 and Figure 91). The daily temperatures, dew point temperature, solar radiation and wind speeds exhibit no anomalies and are consistent with the other station. The dew point depression from minimum air temperature, K_o, pattern is appears to be greater than the other stations with 103 days exhibiting depressions greater than 5C compared to 78, 9, 28 and 39 days (IFAI, OSGI, SHLI and TERI) for the period between April 1st and September 30th. The solar radiation, R_s, appears to be fine when compared to R_{so} and R_{so*}. Wind speeds are appropriate and visually comparable to those of the other stations. The precipitation record shows no anomalies; however, mid-summer precipitation frequency and amounts are not supported by all the neighboring stations. The January through November cumulative ET_r based on the non-quality controlled data was 1647 mm (113% of the AWS average) which is approximately 300 mm higher than neighboring stations

Adjustments: The solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5C which impacted 85 days during the period from April 1st to September 30th.

Laketown, UT (LAKU)

The LAKU station is part of the AgWxNet/UCC network and has been assimilated in to the PN-Agrimet data archival and reporting system. The station is located outside the study and is included in the AWS station set to provide anchoring of interpolation images for the entire study area. The anemometer height has been assumed to be 3-meters. There are no neighboring stations within 35km. The meteorological time series for this station are shown in Figure 59. The air temperature, dew point, solar radiation, and wind speed time series exhibit no anomalies. The dew point depression for this station appears to be consistent with weather stations located within irrigated agricultural areas. The solar radiation appears to be low when compared to the "clear day" R_s/R_{so} ratios. The cumulative January through November ET_r for this station was 1354 mm prior to adjustments (93% of average for all stations).

Adjustments: The solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5C which impacted 85 days during the period from April 1st to September 30th.

Leadore Creek, ID (LDOI1)

The LDOI1 station is a RAWS network station. This station is located in the study area (Path 40 Row 29) and has historically been used with METRIC. The wind anemometer height is assumed to be 6.1-meter based on standard RAWS station configurations. There are no neighboring stations within 35km. Figure 60 shows the meteorological data time series associated with the station. For near real time processing, the station was assumed to be arid and the ETIdaho K_o was applied in the fashion described for CHRI1. The air temperature, dew point, precipitation, and wind speed time series do not exhibit any anomalies of concern. Some of the non PN-Agrimet network stations thought to be in agricultural settings (NiceNet, AgWxNet, GP-Agrimet) exhibit similar dew point depressions as this station. The solar radiation series looks good when compared to "clear day" R_s/R_{so} ratios with exception of February 22nd associated with a single day missing record on the 21st. The prior to adjustment cumulative January through November ET_r for this station was 1355 mm (93% of AWS average).

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 58 days during the period from April 1st through September 30th. The solar radiation observation for February 22nd was set to the clear sky value.

Lewiston, UT (LEWU)

The LEWU station is part of the AgWxNet/UCC network and has been assimilated in to the PN-Agrimet data archival and reporting system. The anemometer height has been assumed to be 3-meters. The meteorological time series for this station are shown in Figure 61. The station has three neighboring stations within 35 km: EVFU, PSTI and TRMU (Figure 46, Figure 73 and Figure 93). The air temperature, dew point, precipitation, solar radiation and wind speed time series have no anomalies and compare well with those at the neighboring stations. The dew point depression for this station exhibits characteristics of a humid location, significantly lower than the depressions observed at the neighboring stations. The solar radiation series compares well to the other stations and "clear day" solar radiation compares well with R_s/R_{so} ratios. The wind speed series compares well with the neighbors. Precipitation for this station appears to have anomalies when compared to the EVFU and TRMU stations. The cumulative January through November ET_r for this station was 1232 mm (85% of AWS average) for the non-adjusted data

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted only 1 day during the period from April 1st through September 30th. The precipitation record was reviewed and modified based on PSTI, EVFU, and TRMU stations.

Malta, ID (MALI)

The MALI station is a Pacific Northwest Agrimet network station and is a historical ETIdaho station. This station is assumed to be located in an agricultural setting with an anemometer height of 3 meters. The meteorological time series for the station are shown in Figure 62. This station has no neighboring AWS stations located within 35 km. The air temperature, dew point, precipitation, solar radiation and wind speed time series appear to be appropriate with no anomalies. The dew point depression exhibits the behavior for stations located in a slightly arid agricultural setting. The solar radiation appears to be to fine when compared to "clear sky" R_s/R_{so} ratios. The wind speed record does not appear to have any issues. The period of record, January through November, ET_r is 1571 mm (108% of AWS average) prior to adjustments.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios even for the June and July period. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 20 days during the period from April 1st through September 30th.

Minidoka, ID (MDKI)

The MDKI station is a INL/NOAA station which PN-Agrimet has incorporated into their system. The anemometer height is 15 m above ground surface. The meteorological time series for this station are shown in Figure 63. The station has one neighboring stations within 35 km: RPTI (Figure 79). The air temperature, dew point, solar radiation, and precipitation series exhibit no anomalies and compare favorably with the neighboring station. The dew point depression from minimum air temperature is similar to RPTI and is similar to what would be expected for a station located within irrigated agriculture. The solar radiation appears to high when compared to "clear sky" R_s/R_{so} ratios. The wind speed is slightly lower than RPTI. The cumulative January through November ET_r for this station was 1578 mm (108% of AWS average) based on non-adjusted data and is approximately 100 mm higher than RPTI.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 9 days during the period from April 1st through September 30th.

Montpelier, ID (MNPI)

The MNPI station is a Pacific Northwest Agrimet station with a 3m anemometer height. This station located outside the study area provides control for interpolated surfaces along the edge of the study area (an anchor station). The meteorological data series for the station are shown in Figure 64. The data series for all the parameters look good and there no issues with the exception of solar radiation. The K_o time series indicates that the station is probably representative of an agricultural setting. The solar radiation appears to low when compared to "clear sky" R_s/R_{so} ratios. The period of record ET_r for MNPI was 1194 mm (82% of AWS average) prior to adjustments.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 3 days during the period from April 1st through September 30th.

Monteview, ID (MNTI)

The MNTI station is a joint station between PN-Agrimet and INL and is a historical ETIdaho station. The anemometer is mounted at 2 m above ground surface. The data time series for the various parameters are shown in

Figure 65. Within 35 km of MNTI, three other AWS station are available for comparison: HAMI, TERI and TRTI (Figure 55, Figure 91 and Figure 94). The daily temperatures, dew point temperature, solar radiation and wind speeds exhibit no anomalies and are consistent with the other station. The dew point depression from minimum air temperature, K_o, pattern appears to be less than the other stations with 24 days exhibiting depressions greater than 5C for the period between April 1st and September 30th. The solar radiation, R_s, appears to be fine when compared to "clear sky" R_s/R_{so}. Wind speeds are appropriate and visually comparable to those of the other stations. The precipitation record shows no anomalies. The January through November cumulative ET_r based on the non-quality controlled data was 1419 mm (98% of the AWS average) which is close to that of two neighboring stations.

Adjustments: The solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5C which impacted 6 days during the period from April 1st to September 30th.

Clover Valley, NV (NCLV)

The NCLV station is part of the NiceNet agricultural weather network operated by DRI. The data was initially obtained via MesoWest. The anemometer is assumed to be mounted 3-meters above the ground surface. The station is located outside the study and is included in the AWS station set to provide anchoring of interpolation images for the entire study area. There are no neighboring AWS stations within 35km of this station. The meteorological data time three-day period of missing data from August 16th through August 18th. The data for the missing period was manually obtained from DRI. The air temperature, dew point, precipitation and wind speed show no anomalies with the exception of missing data. The dew point depression from minimum air temperature, k_o, does have values exceeding those associated with a station in a well irrigated area. The solar radiation series has outliers throughout the period but on average appear to be low when compared to "clear sky" daily R_s/R_{so} ratios. The January through November cumulative ET_r based on the non-quality controlled data was 1544 mm (106% of the AWS average).

Adjustments: The solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5C which impacted 32 days during the period from April 1st to September 30th. The data set from MesoWest archive was updated to reflect that in the DRI/WRRC data server to fill in the missing period prior to adjusting solar radiation and limiting the dew point depression from minimum air temperature.

Nampa, ID (NMPI)

The NMPI station is part of the PN-Agrimet network and a historical ETIdaho station. The station is outside of the study area and is only included for the interpolation of surfaces. The anemometer height has been assumed to be 3-meters. The meteorological time series for the station are shown in Figure 67. The station has no neighboring stations within 35 km. The temperature series do not exhibit any anomalies. The dew point depression for the station are consisted with other historical AWS ETIdaho stations located in irrigated areas. The solar radiation series is consisted with "clear sky" R_s/R_{so} ratios; however, the values appear to be consistently high. The daily wind speeds exhibit no anomalies. The cumulative January through November ET_r for this station was 1621 mm (111% of AWS average).

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 24 days during the period from April 1st through September 30th.

Ontario, OR (ONTO)

The ONTO station is part of the PN-Agrimet network. The station is outside of the study area and is only included for the interpolation of surfaces. The anemometer height has been assumed to be 3-meters. The meteorological time series for the station are shown in Figure 68. The station has one neighboring stations within 35 km: PMAI (Figure 72). The temperature series do not exhibit any anomalies. The dew point depression for the station are consisted with other historical AWS ETIdaho stations located near desert areas and is higher than those at PMAI. The solar radiation series is consisted with "clear sky" R_s/R_{so} ratios; however, the values appear to be high. The daily wind speeds exhibit no anomalies. The cumulative January through November ET_r for this station was 1670 mm (115% of AWS average) and compares to 1527 mm for PMAI based on non-adjusted data.

Adjustments: Because this station is located outside the study area and the nearby station PMAI reflects a more irrigated setting, this station was dropped from the final processing. If this station was to be retained, the solar radiation should be adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature should be limited to 6.5 C which would impact 85 days during the period from April 1st through September 30th.

Osgood, ID (OSGI)

The OSGI station is a Pacific Northwest Agrimet network station. This station is assumed to be located in an agricultural setting with an anemometer height of 3 meters. The meteorological time series for the station are shown in Figure 69. This station has seven neighboring AWS station located within 35 km: IFAI, KTBI, RGBI, ROBI, RRII, SHLI and TRTI (Figure 57, Figure 58, Figure 77, Figure 78, Figure 81 and Figure 94). The air temperature time series appear to be appropriate with no anomalies and compares favorably with the other stations. The dew point and depression exhibit the behavior for stations located in an irrigated agricultural setting and appears to be typically lower than most of the other stations. There is concern about dew point and dew point depression during the month of October, it does not exhibit day to day variation. During April through September period; only 9 days exhibit dew point depressions greater than 5C. The solar radiation appears to correct when compared to "clear sky" R_s/R_{so} ratios. The wind speed record does not appear to have any issues. The period of record, January through November, ET_r is 1377 mm (95% of AWS average) prior to adjustments. This approximately 200 mm lower than the average of the neighboring stations with complete record.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios even for the June and July period. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 5 days during the period from April 1st through September 30th. The October period dew point was not adjusted because of the wet October and end of season.

Howe, ID (OWEI)

The OWEI station is a INL/NOAA station which PN-Agrimet has incorporated into their system. The anemometer height is 15 m above ground surface. The meteorological time series for this station are shown in Figure 70. The station has one neighboring stations within 35 km: RRCI (Figure 80). The air temperature, dew point, solar radiation, precipitation and wind speed series exhibit no anomalies and compare favorably with the neighboring station. The dew point depression from minimum air temperature is higher typically than RRCI and is similar to what would be expected for a station located in an irrigated area next to a desert. The solar radiation appears to ok when compared to "clear sky" R_s/R_{so} ratios. The cumulative January through November ET_r for this station was 1633 mm (112% of AWS average) based on non-adjusted data. Because RRCI has a 27-day missing period during the summer, the ET_r cannot be compared.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 48 days during the period from April 1st through September 30th.

Picabo, ID (PICI)

The PICI station is a Pacific Northwest Agrimet network station and is a historical ETIdaho station. This station is assumed to be located in an agricultural setting with an anemometer height of 3 meters. The meteorological time series for the station are shown in Figure 71. This station has one neighboring AWS stations located within 35 km: ICHI (Figure 56). The air temperature, dew point, precipitation, solar radiation and wind speed time series appear to be appropriate with no anomalies and compare favorably with ICHI. The dew point depression exhibits the behavior for stations located in a slightly arid agricultural setting next to a desert area. The solar radiation appears to be to fine when compared to "clear sky" R_s/R_{so} ratios. The wind speed record does not appear to have any issues and shows values expected for a station located in a more sheltered environment such a valley compared to that for ICHI located on the Snake River plain. The period of record, January through November, ET_r is 1370 mm (94% of AWS average) prior to adjustments and compares to 1685 mm for ICHI.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios even for the June and July period. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 55 days during the period from April 1st through September 30th.

Parma, ID (PMAI)

The PMAI station is part of the PN-Agrimet network and a historical ETIdaho station. The station is outside of the study area and is only included for the interpolation of surfaces. The anemometer height has been assumed to be

3-meters. The meteorological time series for the station are shown in Figure 72. The station has one neighboring stations within 35 km: ONTO (Figure 68). The air temperature, dew point, precipitation, solar radiation and wind speed series do not exhibit any anomalies. The dew point depression for the station are consisted with other historical AWS ETIdaho stations located in irrigated areas and appears to more appropriate for irrigated areas that those at ONTO. The solar radiation series is consisted with "clear sky" R_s/R_{so} ratios; however, the values appear to be consistently high. The daily wind speeds exhibit no anomalies. The cumulative January through November ET_r for this station was 1572 mm (105% of AWS average) for non-adjusted data and is lower than that for ONTO (1670 mm).

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 19 days during the period from April 1st through September 30th.

Preston, ID (PSTI)

The PSTI station is a PN Agrimet network station and has an anemometer height of 3-meters. This station has one neighboring AWS stations within 35 km, LEWU. The meteorological time series for this station are shown in Figure 73 and exhibit similar trends and patterns as those at LEWU (Figure 61). The minimum and maximum air temperature series exhibit no anomalies. The average dew point temperature and depression from minimum appears to be representative of a slightly arid irrigated area during the July through September period when compared to LEWU. The solar radiation appears to be slightly low when compared to the "clear day" R_s/R_{so} ratios. The precipitation record shows two anomalies with daily precipitation above 45 mm/day (72 mm on July 7th and 45 mm on August 10th). Neither event is supported by the precipitation record at LEWU. The daily average wind speeds are similar to those at LEWU. The cumulative January through November ET_r for this station was 1305 mm prior to adjustments (90% of average for all stations) which compares to 1232 mm LEWU.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 8 days during the period from April 1st through September 30th. Precipitation record was adjusted based on record at LEWU and it's neighbors.

Paradise Valley, NV (PVLN2)

The PVLN2 station is part of the NiceNet agricultural weather network operated by DRI. The anemometer is assumed to be mounted 3-meters above the ground surface. The station is located outside the study and is included in the AWS station set to provide anchoring of interpolation images for the entire study area. There are no neighboring AWS stations within 35km of this station. The air temperature, dew point, precipitation and wind speed show no anomalies with the exception of missing data. The dew point depression from minimum air temperature, K_o, does have values exceeding those associated with a station in a well irrigated area and are more typical of agricultural setting next to a desert area. The solar radiation series has values that are close to being outliers throughout the period but on average appear to be high when compared to "clear sky" daily R_s/R_{so} ratios. The January through November cumulative ET_r based on the non-quality controlled data was 1897 mm (130% of the AWS average).

Adjustments: The solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5C which impacted 102 days during the period from April 1st to September 30th.

Park Valley, UT (PVLU1)

The PVLU1 station is part of the USDA/NRCS SCAN (Soil Climate Analysis Network). Based on generic documentation and photograph of typical SCAN station, the anemometer (wind speed) sensor has been assumed to be mounted 3-meters above the ground surface. Initially, it was assumed to be at 6.1 meters. The meteorological data time series for this station are shown in Figure 75. The station has no neighboring AWS stations within 35 km. The maximum air temperature and precipitation series have anomalies. The average daily dew point depression from minimum air temperature is typical of a station located in non-irrigated agricultural areas. The precipitation event on October 16th of 45 mm appears to be faulty; however, the two closest AWS stations support the precipitation event. The solar radiation series appear to be low when compared to "clear sky" daily R_s/R_{so} ratios for the summer months. The wind speeds exhibit no anomalies even when translated based on the faulty 6.1 meter mounting assumption. The January through November cumulative ET_r based on the non-quality controlled data was 1377 mm (95% of the AWS average).

Adjustments: The solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5C which impacted 107 days during the period from April 1st to September 30th. The wind speed sensor height was corrected from 6.1 to 3 meters.

Ruby River Valley, MT (RBYM)

The RBMY station is a GP Agrimet network station. The anemometer height was assumed to be 2 meters. The station is located in the northern portion of the study area. The meteorological time series are shown in Figure 76. The DLNM station (Figure 42) is located within 35 km of this station. The minimum and maximum temperature series exhibit no anomalies. The average daily dew point temperature and depression from minimum appears to be representative of an irrigated area and is typically larger than that at DLNM. The solar radiation appears to be fine when compared to the "clear day" R_s/R_{so} ratios with exception of the period from August through November. The wind speed show a depressed period in July; however, this is also apparent at the DLNM station. The cumulative January through November ET_r for this station was 1427 mm (98% of average for all stations) and compares to 1291 at DLNM.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 59 days during the period from April 1st through September 30th.

Rigby, ID (RGBI)

The RGBI station is a Pacific Northwest Agrimet network station. This station is assumed to be located in an agricultural setting with an anemometer height of 3 meters. The meteorological time series for the station are shown in Figure 77. This station has seven neighboring AWS station located within 35 km: IFAI, OSGI, ROBI, RRII, RXGI, SHLI and SUGI (Figure 57, Figure 69, Figure 78, Figure 81, Figure 83, Figure 85 and Figure 89). The air temperature time series appear to be appropriate with no anomalies and compares favorably with the other stations. The dew point and depression exhibit the behavior for stations located in a slightly arid irrigated agricultural setting and appears to be similar to most of the other stations. The precipitation record is similar to the other stations. The solar radiation appears to correct when compared to "clear sky" R_s/R_{so} ratios. The wind speed record does not appear to have any issues that are not found in other stations. The period of record, January through November, ET_r is 1609 mm (111% of AWS average) prior to adjustments. This approximately 150 mm higher than the average of the neighboring stations with complete record.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios even for the June and July period. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 47 days during the period from April 1st through September 30th.

Roberts, ID (ROBI)

The ROBI station is a Pacific Northwest Agrimet network station. This station is assumed to be located in an agricultural setting with an anemometer height of 3 meters. The meteorological time series for the station are shown in Figure 78. This station has nine neighboring AWS station located within 35 km: HAMI, IFAI, KTBI, OSGI, RGBI, RXGI, SHLI, TERI and TRTI (Figure 55, Figure 57, Figure 58, Figure 69, Figure 77, Figure 83, Figure 85, Figure 91 and Figure 94). This station has missing data from June 11th through July 12th. The air temperature time series appear to be appropriate and compares favorably with the other stations. The dew point and depression exhibit the behavior for stations located in a slightly arid irrigated agricultural setting and appears to be similar to most of the other stations. The precipitation record is similar to the other stations. The solar radiation appears to correct when compared to "clear sky" R_s/R_{so} ratios; however, after July 12th it appears to be slightly high. The wind speed record does not appear to have any issues that are not found in other stations. Because of the missing data period no comparisons to non-adjusted January through November, ET_r was made.

Adjustments: Due to the missing data period during the summer and with neighboring stations, this station was omitted from the final processing. If this station was to be retained solar radiation and dew point adjustments should be performed as outline for other stations. The missing data would have to be estimated from the other nearby stations in some fashion.

Rupert, ID (RPTI)

The RPTI station is part of the PN-Agrimet network and a historical ETIdaho station. The anemometer height has been assumed to be 3-meters. The meteorological time series for the station are shown in Figure 79. The station has one neighboring stations within 35 km: MDKI (Figure 63). The air temperature time series have an anomaly on February 24th with minimum and maximum air temperatures of -33C and 30C. The average dew point temperature time series does not visually appear to have any issues as well as the precipitation and wind speed series. The solar radiation series appears to have issues from January 29th through February 24th were daily values are close to zero. A station maintenance (calibration event) appears to have occurred during early July. The dew point depression for the station are consisted with other historical AWS ETIdaho stations located in irrigated areas and to those at MDKI. The cumulative January through November ET_r for this station was 1668 mm (115% of AWS average) for non-adjusted data and is higher than that for MDKI (1578 mm).

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios with the missing period (January 29th through February 24th) replaced by the solar radiation measured at MDKI. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 13 days during the period from April 1st through September 30th. The air temperatures for February 24th were taken from MDKI.

Arco, ID (RRCI)

The RRCI station is a INL/NOAA station which PN-Agrimet has incorporated into their system. The anemometer height is 15 m above ground surface. The meteorological time series for this station are shown in Figure 80. The station has one neighboring stations within 35 km: OWEI (Figure 70). This station has missing data from June 15th through July 13th. With the exception of the missing period, the air temperature, dew point, solar radiation, precipitation and wind speed series exhibit no anomalies and compare favorably with the neighboring station. The dew point depression from minimum air temperature is lower typically than OWEI and is similar to what would be expected for a station located in an irrigated area next to a desert. The solar radiation appears to ok when compared to "clear sky" R_s/R_{so} ratios. Because RRCI has a missing period during the summer, the non-adjusted cumulative ET_r cannot be compared.

Adjustments: This station is an important station spatially located on the northern edge of the Eastern Snake Plain Aquifer near Arco. To estimate meteorological data for this station, the RAWS station located near Arco (ARCI1 located 7.5km from RRCI) was obtained and evaluated and regression equations developed. Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C.

Ririe, ID (RRII)

The RRII station is a Pacific Northwest Agrimet network station. This station is assumed to be located in an agricultural setting with an anemometer height of 3 meters. The meteorological time series for the station are shown in Figure 81. This station has five neighboring AWS station located within 35 km: IFAI, OSGI, RGBI, RXGI and SUGI (Figure 57, Figure 69, Figure 77, Figure 83 and Figure 89). The air temperature time series appear to be appropriate and compares favorably with the other stations. The dew point and depression exhibit the behavior for stations located in a slightly arid irrigated agricultural setting and appears to be higher than the other stations. The precipitation record is similar to the other stations. The solar radiation appears to correct when compared to "clear sky" R_s/R_{so} ratios. The wind speed record shows an anomaly prior to May. This anomaly is due to a broken anemometer vane confirmed by the PN Agrimet staff. The cumulative January through November ET_r for this station was 1887 mm (126% of AWS average) for non-adjusted data.

Adjustments: Due to the faulty wind speed data, apparent aridity and the number of stations nearby; this station was omitted from the final processing. If this station was to be retained solar radiation and dew point adjustments should be performed as outline for other stations. The wind speed record for the period with the broken sensor would have to be estimated from the other nearby stations in some fashion.

Rathdrum Prairie, ID (RTHI)

The RHTI station is a Pacific Northwest Agrimet network station. The station is outside of the study area and is only included for the interpolation of surfaces. This station is assumed to be located in an agricultural setting with an anemometer height of 3 meters. The meteorological time series for the station are shown in Figure 82. This station has missing data from October 12th through November 15th. This station has no neighboring AWS station located within 35 km. With the exception of the missing data the air temperature, dew point, wind speed and precipitation time series exhibit no visual anomalies. The dew point and depression exhibit the behavior expected for stations located in an irrigated agricultural setting. The solar radiation series exhibits a sensor calibration issue prior July when it appears to have been corrected using “clear sky” R_s/R_{so} ratios as a reference. The wind speed record does not appear to have any issues. The January through mid October, ET_r is 1060 mm prior to adjustments – one of the lower stations.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted only one day during the period from April 1st through September 30th. Because of the station’s missing data at the end of the season and that it is an anchor station for interpolation surfaces, it was retained without estimating the missing data.

Rexburg, ID (RXGI)

The RXGI station is a Pacific Northwest Agrimet network station and is a historical ETIdaho station. This station is assumed to be located in an agricultural setting with an anemometer height of 3 meters. The meteorological time series for the station are shown in Figure 83. This station has five neighboring AWS stations located within 35 km: AHTI, RGBI, ROBI, RRII and SUGI (Figure 33, Figure 77, Figure 78, Figure 81 and Figure 89). The air temperature, dew point, precipitation, solar radiation and wind speed time series appear to be appropriate with no anomalies. The dew point depression exhibits the behavior for stations located in an irrigated agricultural setting. The solar radiation appears to be high when compared to “clear sky” R_s/R_{so} ratios. The wind speed record does not appear to have any issues. The period of record, January through November, ET_r is 1438 mm (99% of AWS average) prior to adjustments. This is close to the other stations with good data.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios even for the June and July period. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 13 days during the period from April 1st through September 30th.

Slate Creek, ID (SCFI1)

The SCFI1 station is a RAWS network station. This station is outside the study area and is included in the AWS station set to provide anchoring of interpolation images for the entire study area. There are no neighboring stations with in 35 km of its location. The wind anemometer height is assumed to be 6.1-meter based on standard RAWS station configurations. The air temperature, solar radiation, precipitation and wind speed series show no anomalies as shown in Figure 84. For near real time processing, the station was assumed to be arid and the ETIdaho K_o was applied in the fashion described for CHRI1. The average daily dew point depression from minimum air temperature is more consistent throughout the year when compared to other RAWS sites. The solar radiation appears to be low when compared to “clear day” R_s/R_{so} ratios. The wind speeds are low; however, this is probably due to the station’s location in a river canyon (Riggins area) and are similar to those at DENI. The cumulative January through November ET_r for this station was 1195 mm (85% of AWS average) based on non-adjusted data.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 34 days during the period from April 1st through September 30th.

Shelley, ID (SHLI)

The SHLI station is a Pacific Northwest Agrimet network station. This station is assumed to be located in an agricultural setting with an anemometer height of 3 meters. The meteorological time series for the station are shown in Figure 85. This station has six neighboring AWS station located within 35 km: ACKI, IFAI, KTBI, OSGI, RGBI and ROBI (Figure 31, Figure 57, Figure 58, Figure 69, Figure 77 and Figure 78). The air temperature, dew point and wind speed time series appear to be appropriate with no anomalies and compares favorably with the other stations. The dew point and depression exhibit the behavior for stations located in a slightly arid irrigated agricultural setting and appears to be similar to most of the other stations. The precipitation record is similar to the other stations and September 23rd event of 35 mm is supported by the closest stations. The solar radiation appears to correct when compared to “clear sky” R_s/R_{so} ratios. The wind speed record does not appear to have any issues that are not found in other stations. The period of record, January through November, ET_r is 1386 mm (95% of AWS average) prior to adjustments. This approximately 350 mm lower than the average of the neighboring stations with complete record.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios even for the June and July period. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 15 days during the period from April 1st through September 30th.

Salmon, ID (SMYI1)

The SMYI1 station is a RAWS network station. This station is located in the northern section of the study area (Path 40 Row 29) and has historically been used with METRIC. The wind anemometer height is assumed to be 6.1-meter based on standard RAWS station configurations. There are no neighboring stations within 35km. Figure 86 shows the meteorological data time series associated with the station. For near real time processing, the station was assumed to be arid and the ETIdaho K_o was applied in the fashion described for CHRI1. The air temperature, dew point, precipitation, and wind speed time series do not exhibit any anomalies of concern. The solar radiation series looks low when compared to “clear day” R_s/R_{so} ratios. The prior to adjustment cumulative January through November ET_r for this station was 1139 mm (78% of AWS average).

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 114 days during the period from April 1st through September 30th.

Snowville West, UT (SNWU)

The SNWU station is part of the AgWxNet/UCC network and has been assimilated in to the PN-Agrimet data archival and reporting system. The anemometer height has been assumed to be 3-meters. The meteorological time series for this station are shown in Figure 87. The station has one neighboring station within 35 km: BLCU (Figure 35). The temperature time series has no anomalies and compares well with those BLCU. The dew point depression for this station is lower than BLCU. The solar radiation series may be slightly low when compared to “clear sky” R_s/R_{so} ratios. The wind speed series has no anomalies and is typically higher than BLCU. The October precipitation at SNWU is supported by the precipitation records at BLCU and PVLU1. The cumulative January through November ET_r for this station was 1606 mm (111% of AWS average) based on non-adjusted data and is approximately 100 mm higher than BLCU.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 40 days during the period from April 1st through September 30th.

Stanley RS, ID (STNI1)

The STNI1 station is a RAWS network station. This station is located in the northwest section of the study area (Path 40 Row 29). The wind anemometer height is assumed to be 6.1-meter based on standard RAWS station configurations. There are no neighboring stations within 35km. Figure 88 shows the meteorological data time series associated with the station. For near real time processing, the station was assumed to be arid and the ETIdaho K_o was applied in the fashion described for CHRI1. The air temperature, dew point, precipitation, and wind speed time series do not exhibit any anomalies of concern. The solar radiation series looks low when compared to “clear day” R_s/R_{so} ratios with the exception of an visual outlier on February 22nd. The wind speeds are low which may be in part due to the local topography around the station. The prior to adjustment cumulative January through November ET_r for this station was 1089 mm (75% of AWS average).

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The solar radiation outlier on February 22nd was replaced with clear-sky expected value. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 10 days during the period from April 1st through September 30th.

Sugar City, ID (SUGI)

The SUGI station is a INL/NOAA station which PN-Agrimet has incorporated into their system. The anemometer height is 15 m above ground surface. The meteorological time series for this station are shown in Figure 89. The station has four neighboring stations within 35 km: AHTI, RGBI, RRII and RXGI (Figure 33, Figure 77, Figure 81 and Figure 83). The air temperature, dew point, solar radiation, precipitation and wind speed series exhibit no anomalies and compare favorably with the neighboring station. The dew point depression from minimum air temperature is lower typically than the neighboring stations. The solar radiation appears to ok when compared to “clear sky” R_s/R_{so} ratios. The cumulative January through November ET_r for this station was 1500 mm (103% of AWS average) based on non-adjusted data. This is approximately 50 mm lower than the neighboring stations.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 16 days during the period from April 1st through September 30th.

Taber, ID (TABI)

The TABI station is a INL/NOAA station which PN-Agrimet has incorporated into their system. The anemometer height is 15 m above ground surface. The meteorological time series for this station are shown in Figure 90. The station has two neighboring stations within 35 km: ACKI and FHTI (Figure 31 and Figure 50). The air temperature, dew point, solar radiation, precipitation and wind speed series exhibit no anomalies and compare favorably with the neighboring stations. The dew point depression from minimum air temperature is lower than the ACKI station but higher than at FHTI. The solar radiation appears to ok when compared to “clear sky” R_s/R_{so} ratios. The cumulative January through November ET_r for this station was 1652 mm (114% of AWS average) based on non-adjusted data. This is approximately 90 mm higher than the neighboring stations.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 29 days during the period from April 1st through September 30th.

Terreton, ID (TERI)

The TERI station is a INL/NOAA station which PN-Agrimet has incorporated into their system. The anemometer height is 15 m above ground surface. The meteorological time series for this station are shown in Figure 91. The station has five neighboring stations within 35 km: HAMI, KTBI, MNTI, ROBI and TRTI (Figure 55, Figure 58, Figure 65, Figure 78 and Figure 94). The air temperature, dew point, solar radiation, precipitation and wind speed series exhibit no anomalies and compare favorably with the neighboring stations. The dew point depression from minimum air temperature is consistent with irrigated areas. The solar radiation appears to ok when compared to “clear sky” R_s/R_{so} ratios. The cumulative January through November ET_r for this station was 1373 mm (94% of AWS average) based on non-adjusted data. This is approximately 180 mm lower than the neighboring stations average.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 15 days during the period from April 1st through September 30th.

Filer Fairgrounds, ID (TFGI)

The TFGI station is a Pacific Northwest Agrimet network station. This station is assumed to be located in an agricultural setting with an anemometer height of 3 meters. The meteorological time series for the station are shown in Figure 92. This station has one neighboring AWS station located within 35 km: TWFI (Figure 95). The air temperature series has an anomaly for minimum air temperature on September 23rd of -26C. Otherwise the air temperature, dew point and wind speed time series appear to be appropriate and compare favorably with the other station. The dew point and depression exhibit the behavior for stations located in a slightly arid irrigated agricultural setting and appears to be similar to most of the other stations. The solar radiation appears to have had a calibration adjustment around the middle of July correct when compared to “clear sky” R_{so} values. The wind speed record does not appear to have any issues that are not found in other station. The period of record, January through November, ET_r is 1578 mm (108% of AWS average) prior to adjustments. This is similar to the neighboring station.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios even for the June and July period. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 73 days during the period from April 1st through September 30th. The minimum air temperature for September 23rd was modified to be the average of the prior and next days.

Tremonton, UT (TRMU)

The TRMU station is part of the AgWxNet/UCC network and has been assimilated in to the PN-Agrimet data archival and reporting system. The anemometer height has been assumed to be 3-meters. The meteorological time series for this station are shown in Figure 93. The station has three neighboring station within 35 km: CRNU, EVFU and LEWU (Figure 40, Figure 46 and Figure 61). The air and dew point temperature, precipitation, solar radiation and precipitation time series have no anomalies and compares well with those at the nearby stations. The cumulative January through November ET_r for this station was 1633 mm (112% of AWS average) based on non-adjusted data and is approximately 300 mm higher than the nearby station average.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 69 days during the period from April 1st through September 30th.

Terraton, ID (TRTI)

The TRTI station is a Pacific Northwest Agrimet network station. This station is assumed to be located in an agricultural setting with an anemometer height of 3 meters. The meteorological time series for the station are shown in Figure 94. This station has five neighboring AWS station located within 35 km: HAMI, MNTI, OSGI, ROBI and TERI (Figure 55, Figure 65, Figure 69, Figure 78 and Figure 91). The air temperature, dew point and wind speed time series appear to be appropriate and compare favorably with the other stations. The dew point and depression exhibit the behavior for stations located in an irrigated agricultural setting and appears to be similar to most of the other stations. The solar radiation appears to be good when compared to "clear sky" R_{so} values. The wind speed record does not appear to have any issues that are not found in other stations. The period of record, January through November, ET_r is 1486 mm (102% of AWS average) prior to adjustments. This is similar to the neighboring stations.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios even for the June and July period. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 24 days during the period from April 1st through September 30th.

Twin Falls (Kimberly), ID (TWFI)

The TWFI station is a Pacific Northwest Agrimet network station and is a historical ETIdaho station. This station is located in an agricultural setting with an anemometer height of 3 meters. The meteorological time series for the station are shown in Figure 95. This station has one neighboring AWS station located within 35 km: TFGI (Figure 92). The air temperature, dew point and wind speed time series appear to be appropriate and compare favorably with the other station. The dew point and depression exhibit the behavior for stations located in an irrigated agricultural setting and appears to be similar to the other station. The solar radiation appears to need a calibration adjustment when compared to "clear sky" R_{so} values. The wind speed record does not appear to have any issues that are not found in other station. The period of record, January through November, ET_r is 1505 mm (103% of AWS average) prior to adjustments. This is similar to the neighboring station.

Adjustments: Solar radiation was adjusted based on observed clear day R_s/R_{so} ratios even for the June and July period. The dew point depression from minimum air temperature was limited to 6.5 C which impacted 24 days during the period from April 1st through September 30th.

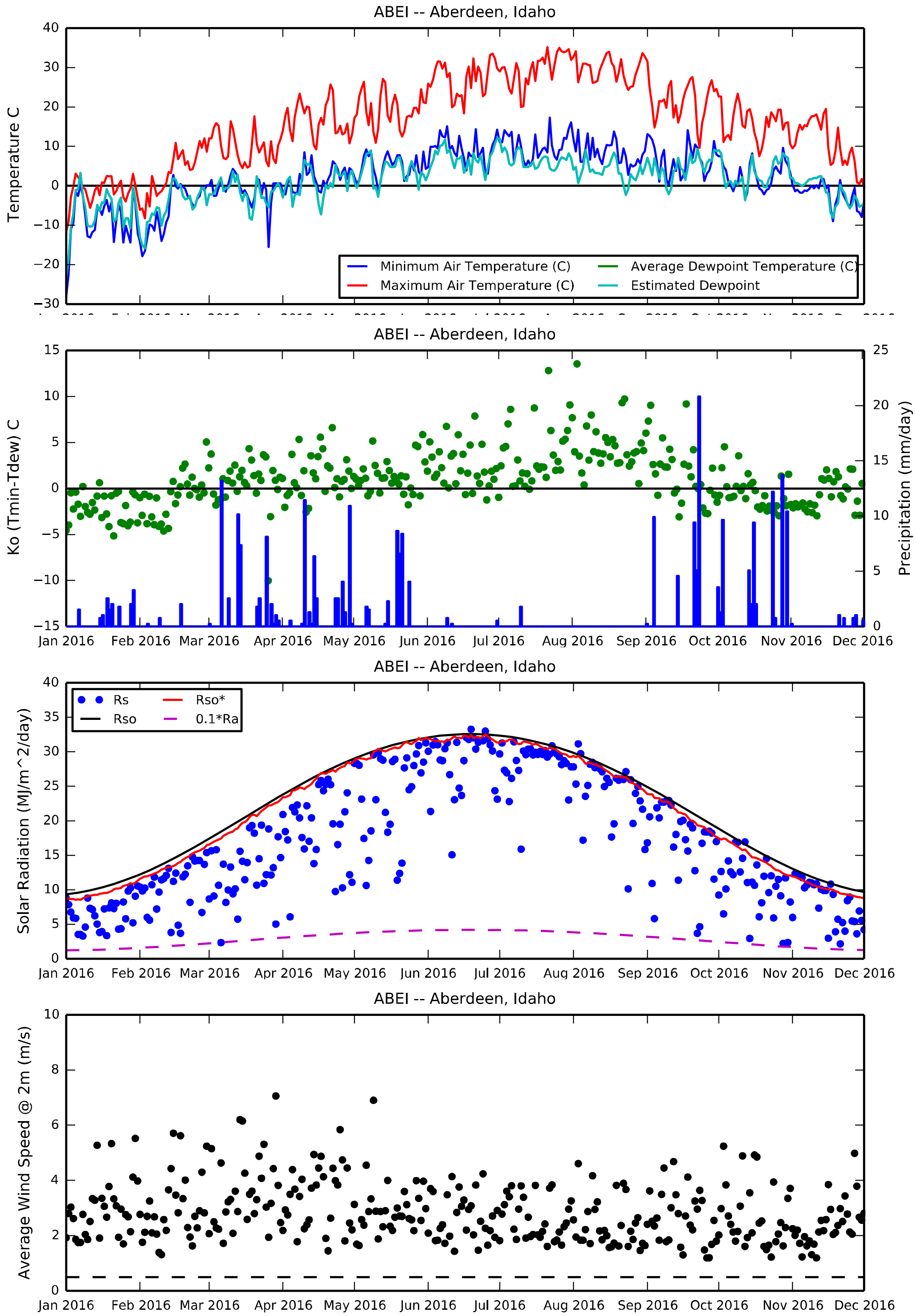


Figure 30. Aberdeen ID (ABEI) meteorological time series (Est.Tdew = Ave.Tdew).

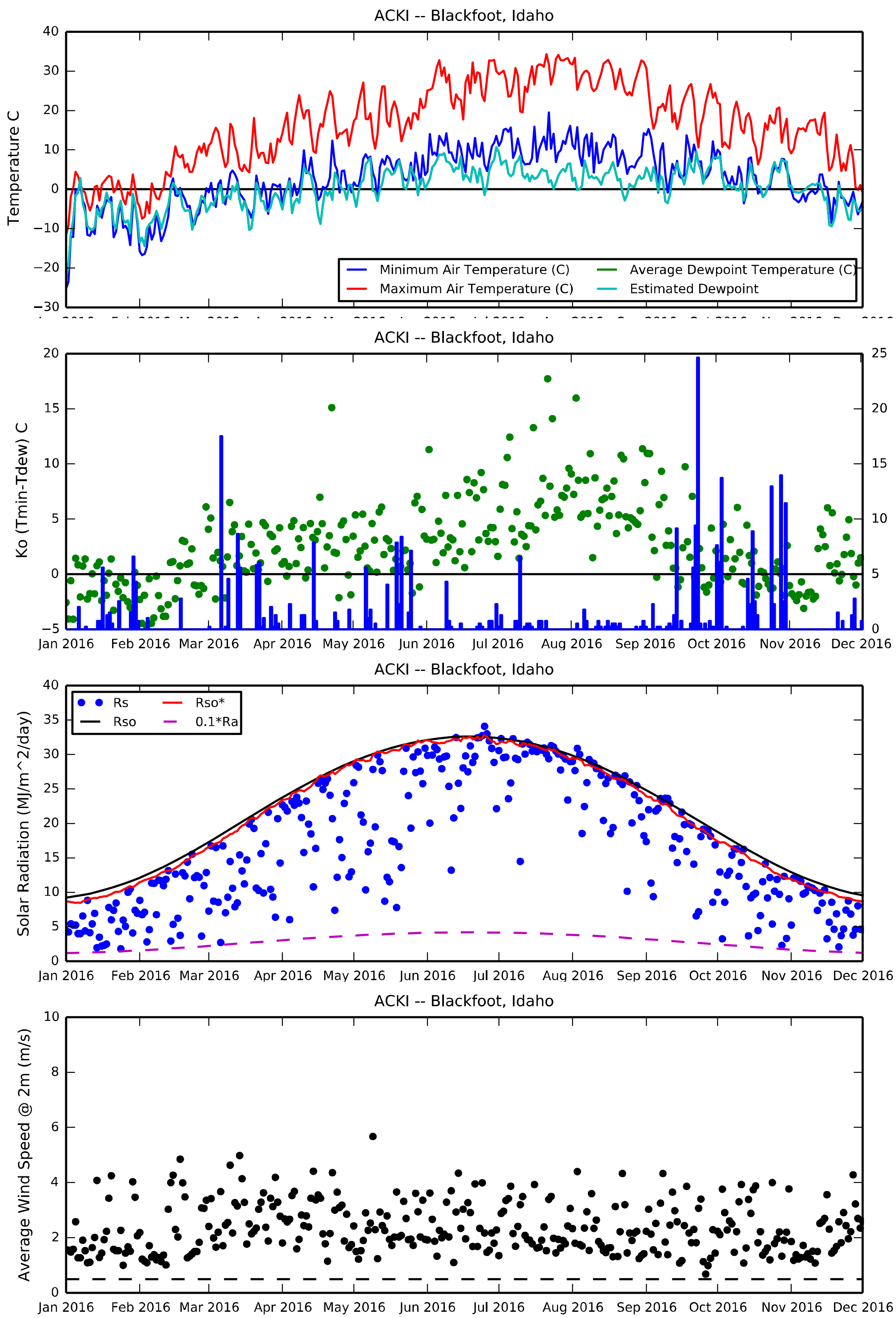


Figure 31. Blackfoot ID (ACKI) meteorological time series (Est.Tdew = Ave.Tdew).

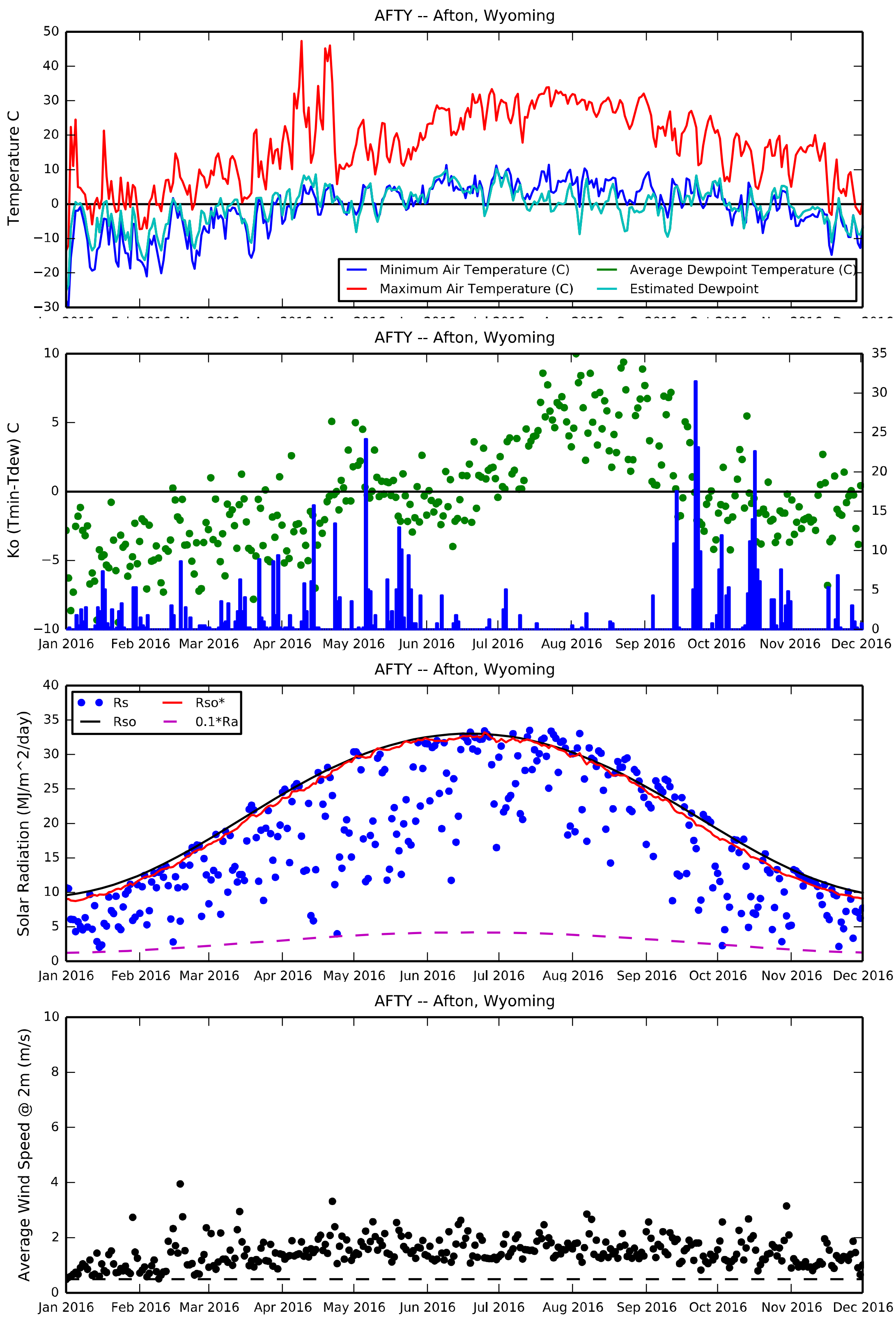


Figure 32. Afton WY (AFTY) meteorological time series (Est.Tdew = Ave.Tdew).

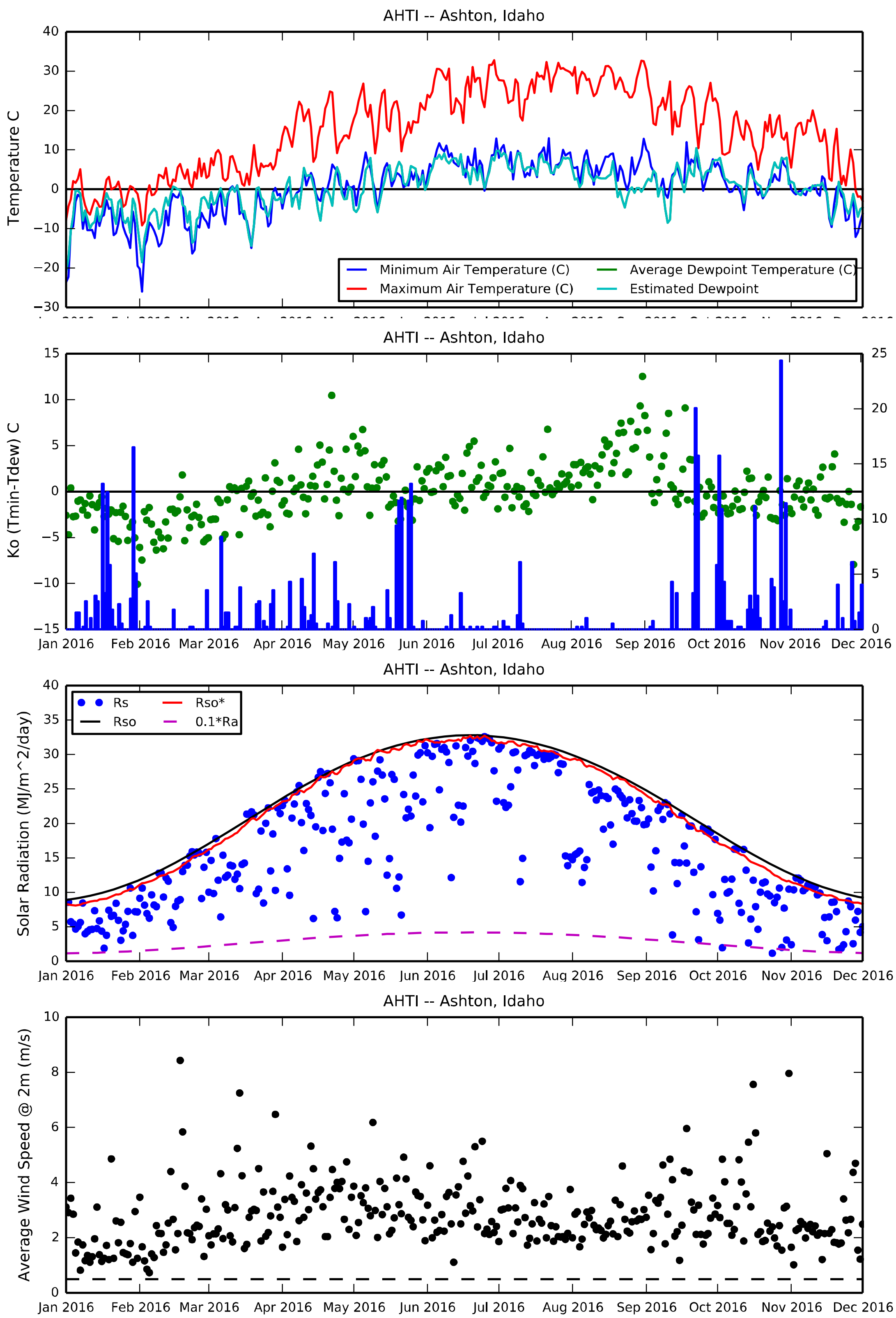


Figure 33. Ashton ID (AHTI) meteorological time series (Est.Tdew = Ave.Tdew).

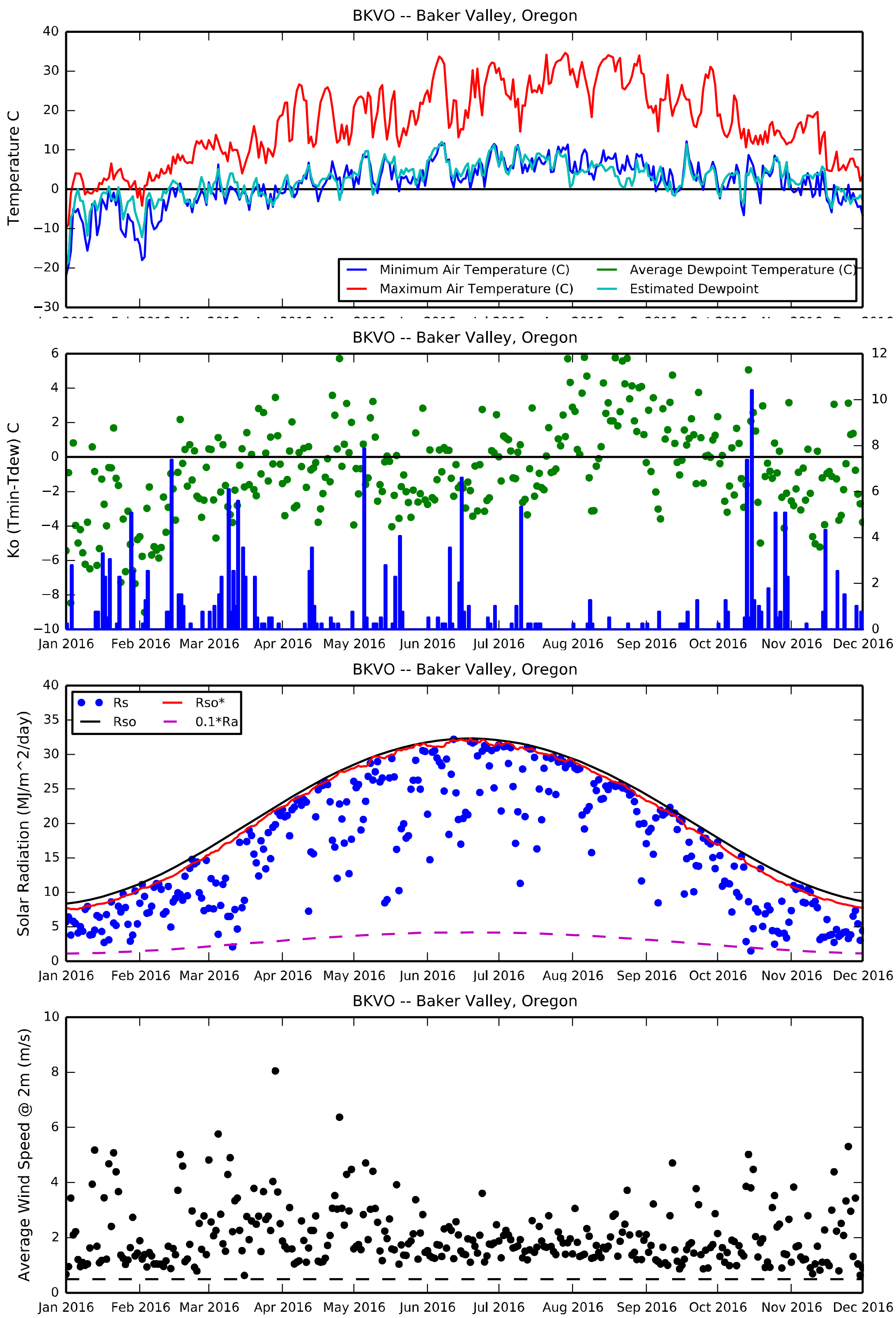


Figure 34. Baker Valley OR (BKVO) meteorological time series (Est.Tdew = Ave.Tdew).

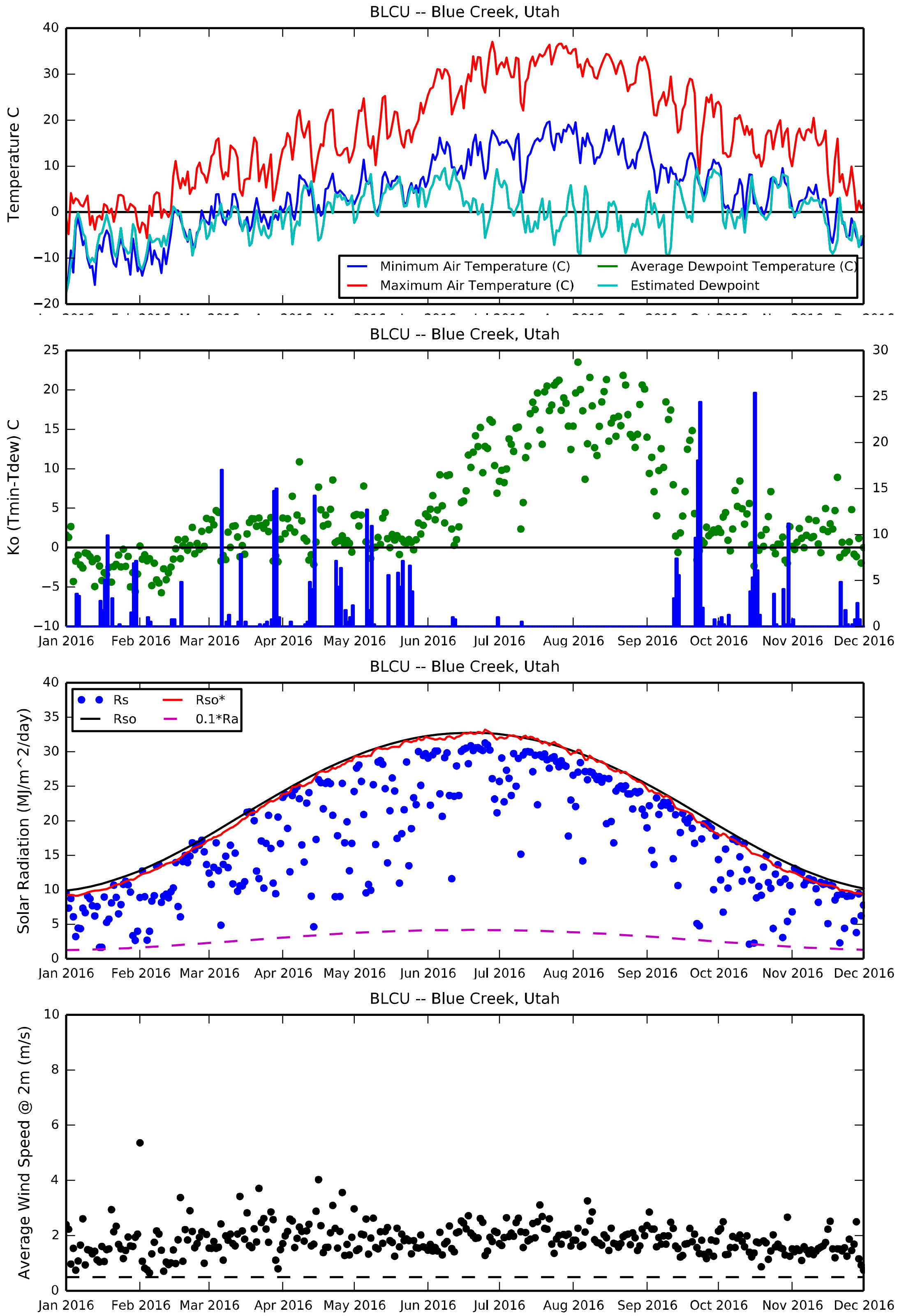


Figure 35. Blue Creek UT (BLCU) meteorological time series (Est.Tdew = Ave.Tdew).

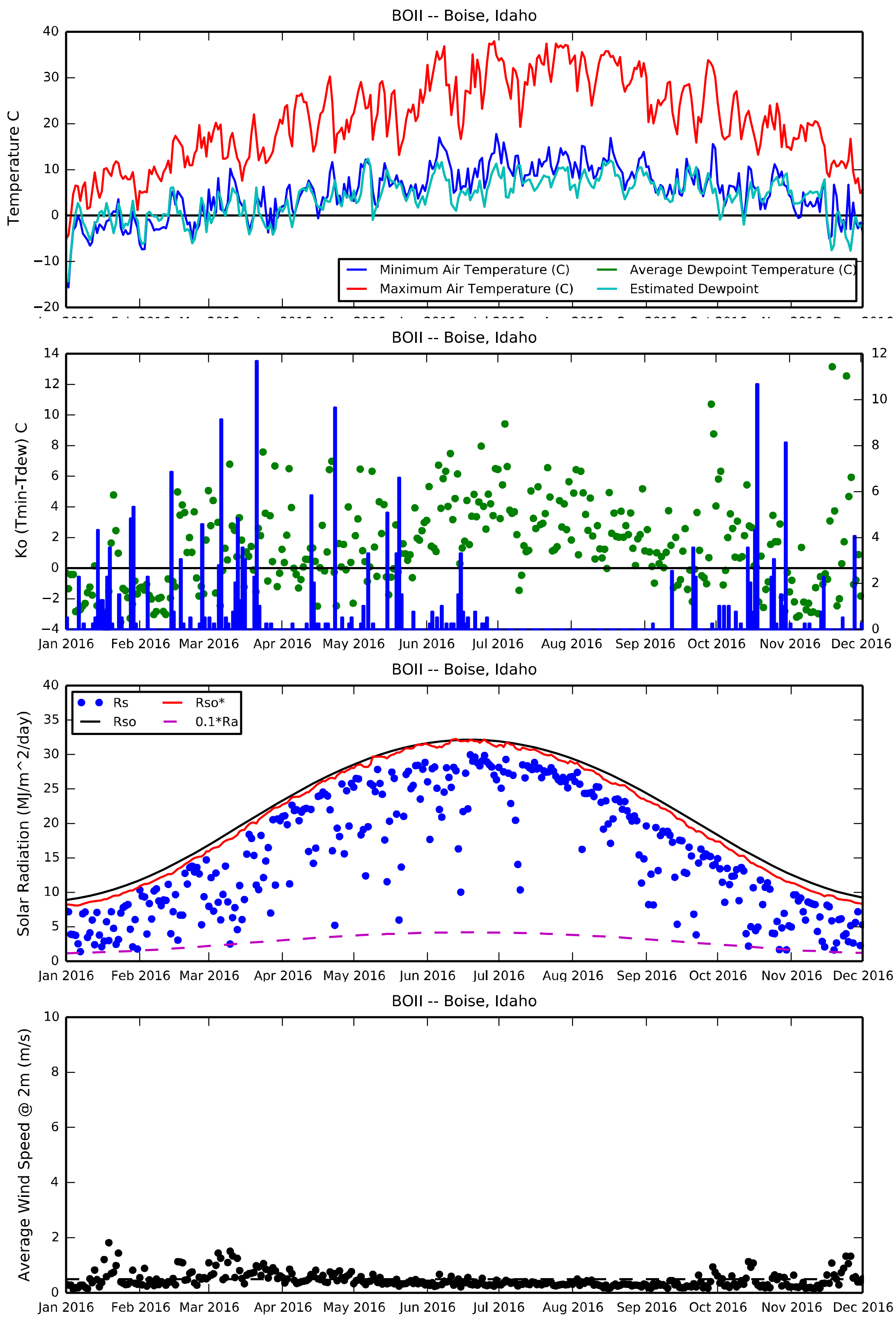


Figure 36. Boise ID (BOII) meteorological time series (Est.Tdew = Ave.Tdew).

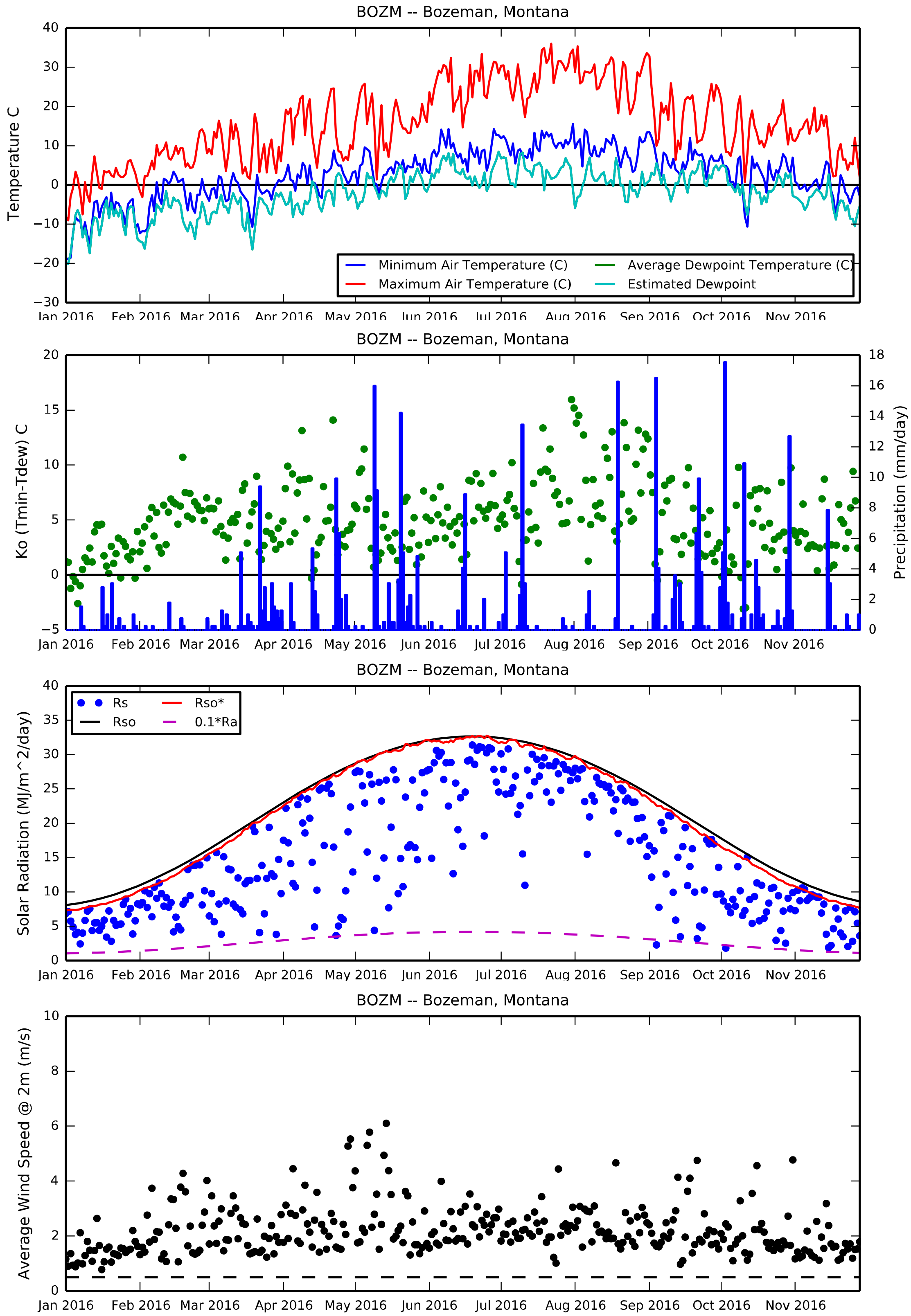


Figure 37. Bozeman MT (BOZM) meteorological time series (Est.Tdew = Ave.Tdew).

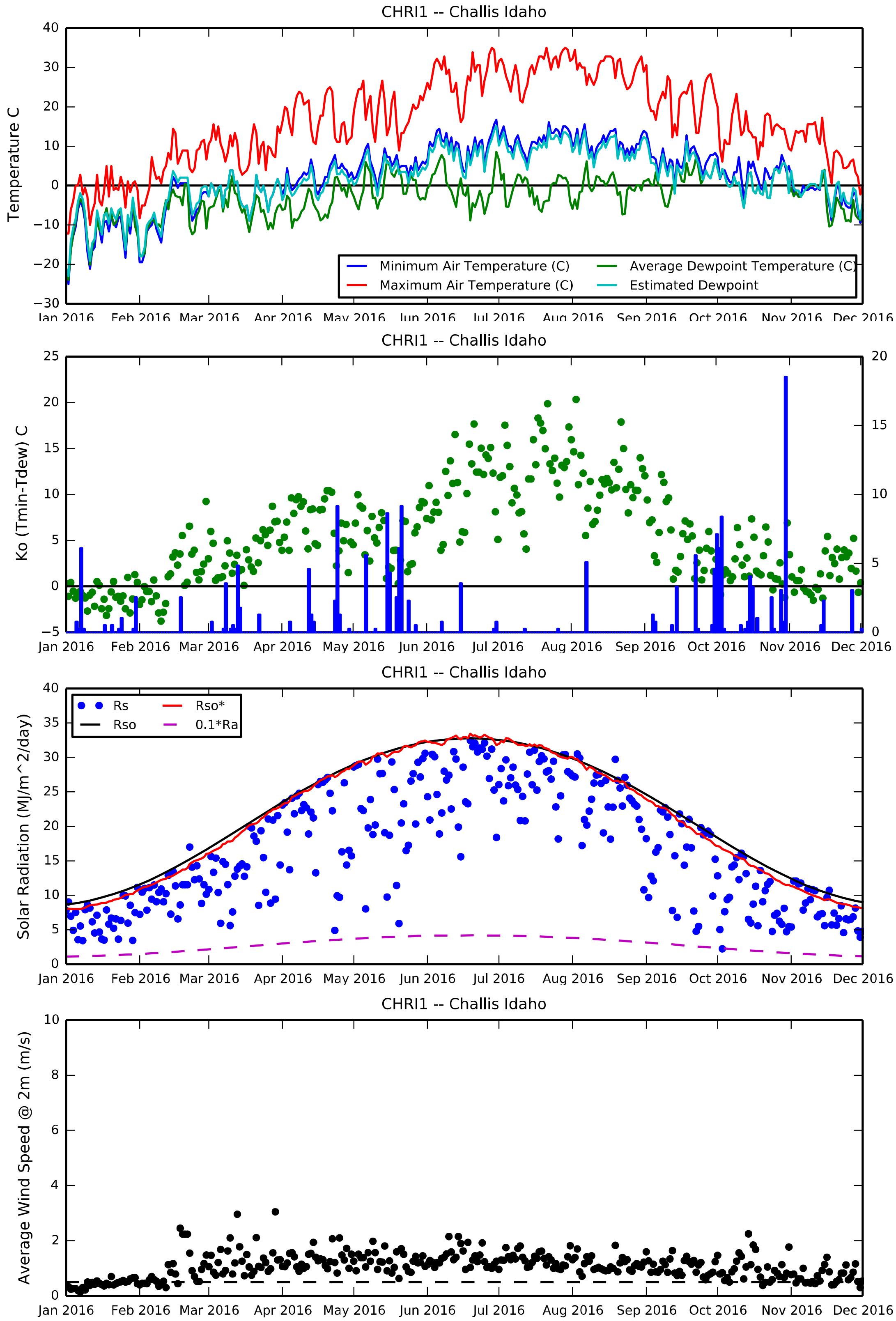


Figure 38. Challis ID (CHRI1) meteorological time series (Est.Tdew = f(K_o, Ave.Tdew)).

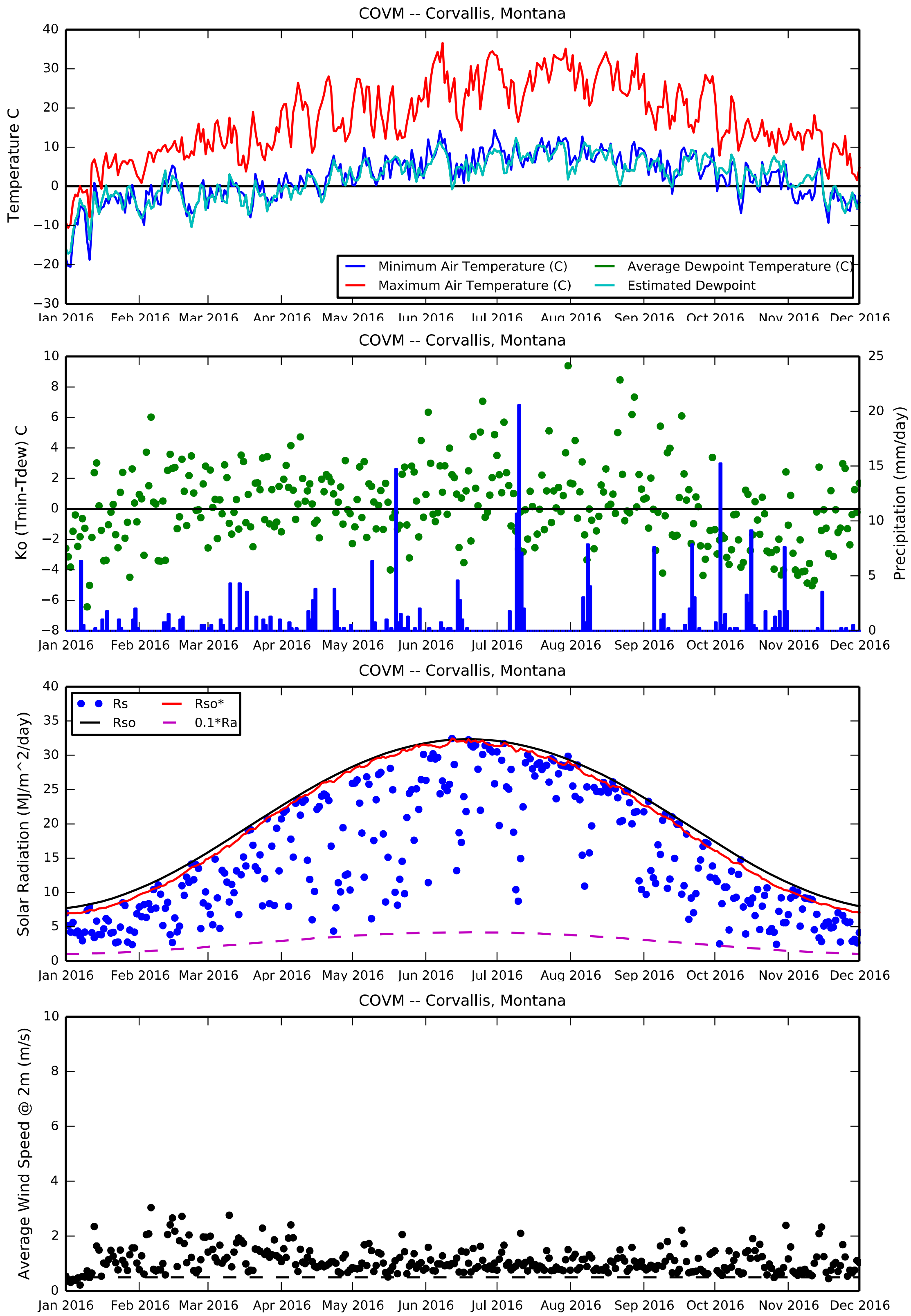


Figure 39. Corvallis MT (COVM) meteorological time series (Est.Tdew = Ave.Tdew).

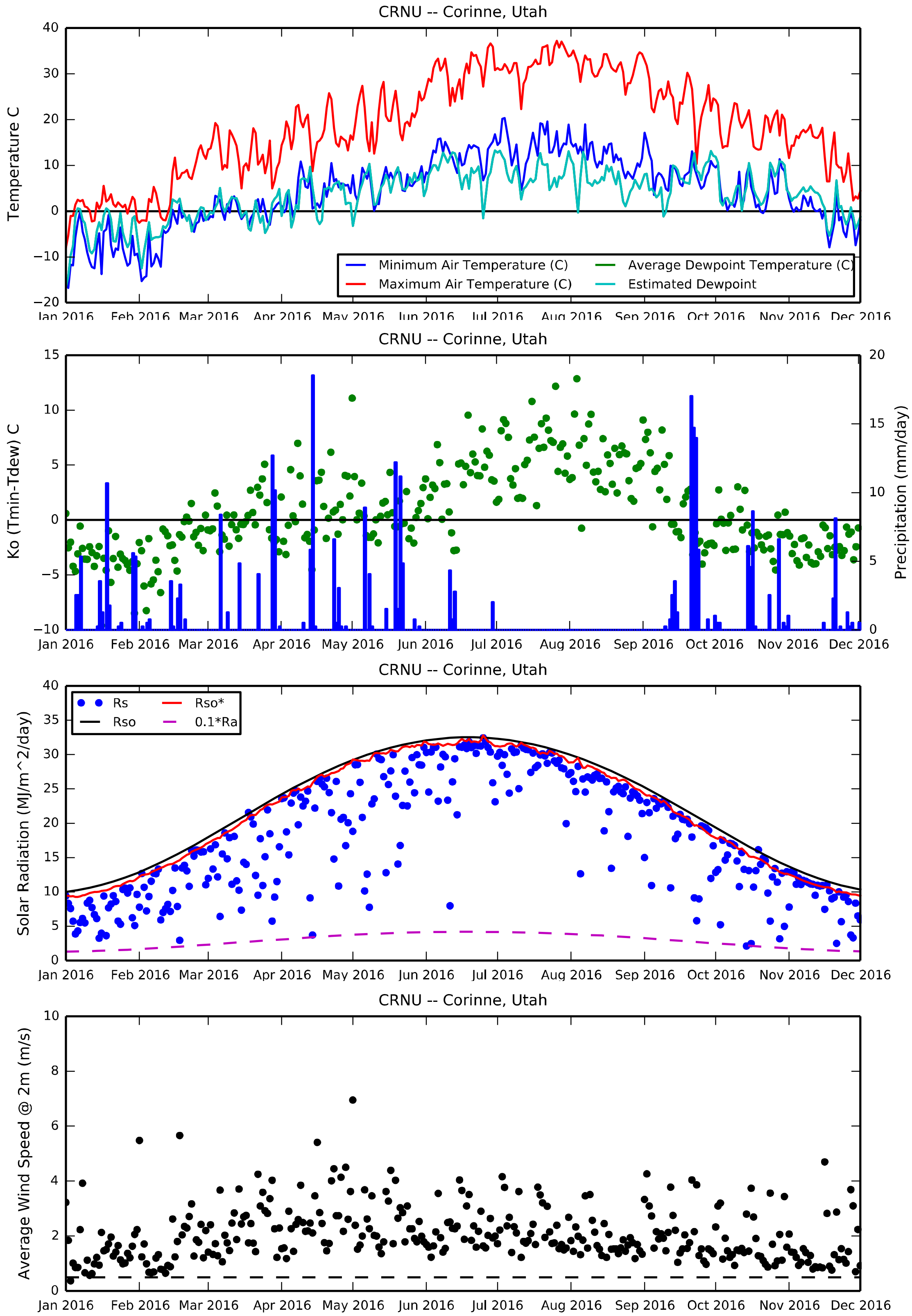


Figure 40. Corinne UT (CRNU) meteorological time series (Est.Tdew = Ave.Tdew).

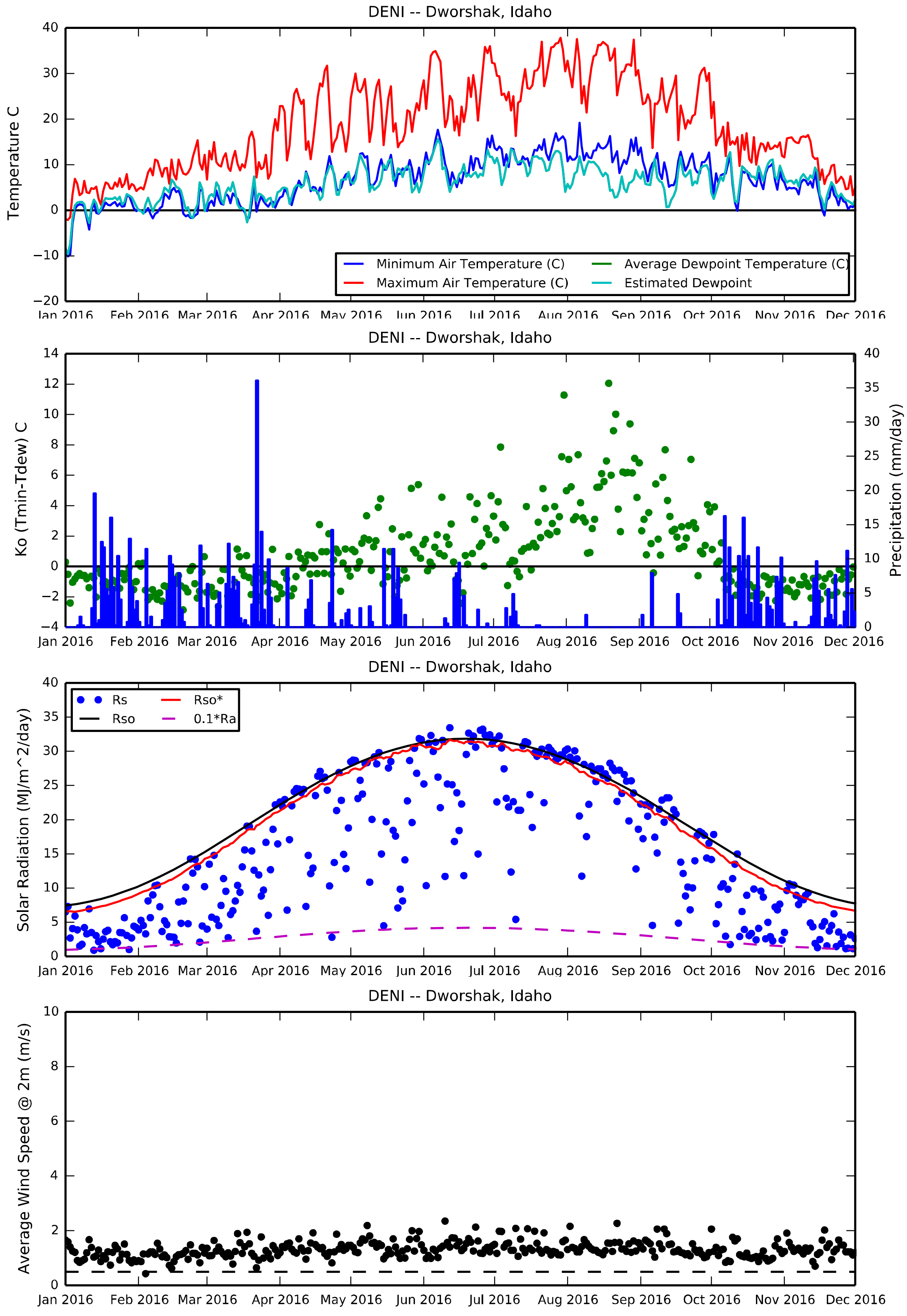


Figure 41. Dworshak ID (DENI) meteorological time series (Est.Tdew = Ave.Tdew).

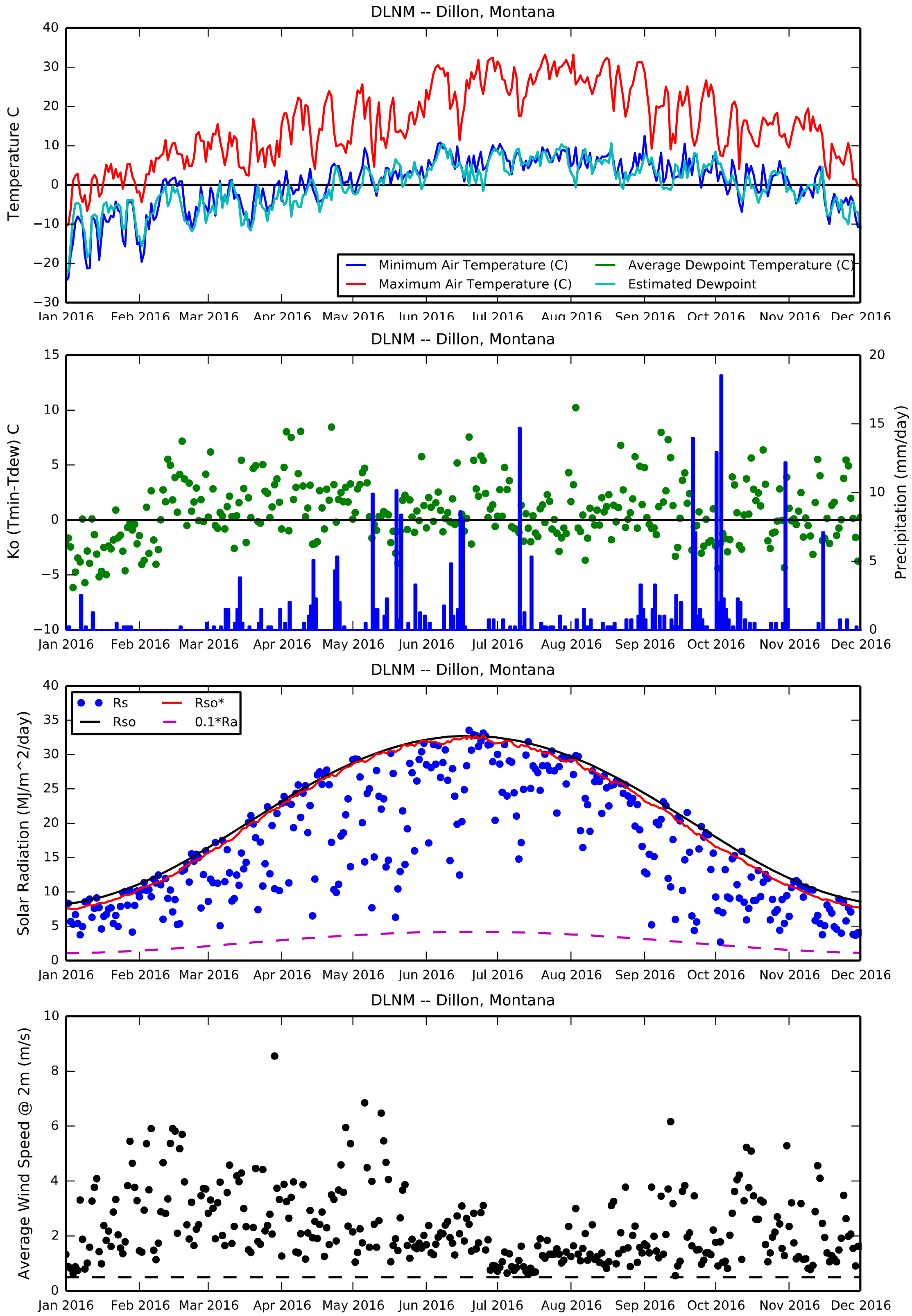


Figure 42. Dillon MT (DLNM) meteorological time series (Est.Tdew = Ave.Tdew).

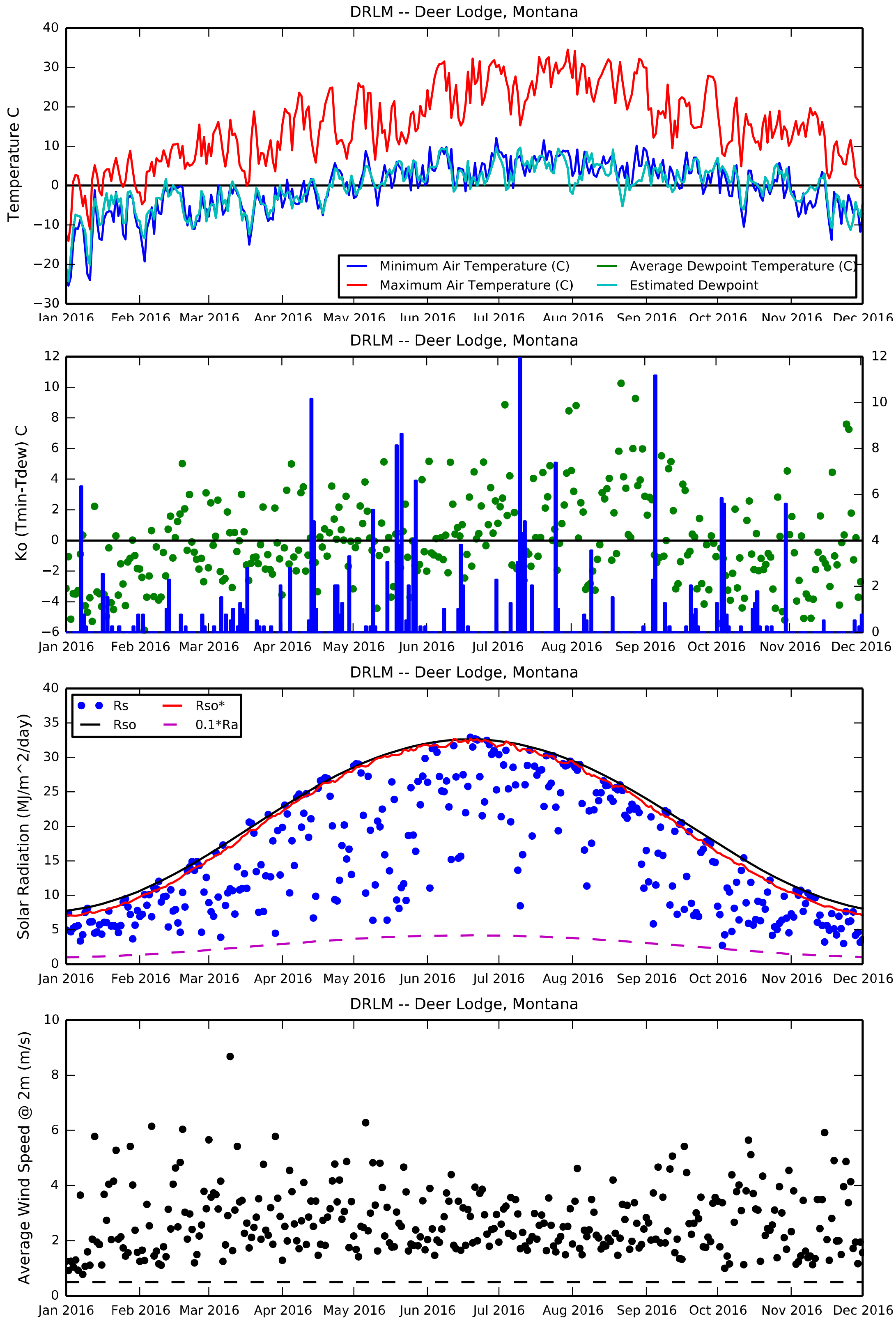


Figure 43. Deer Lodge MT (DRLM) meteorological time series (Est.Tdew = Ave.Tdew).

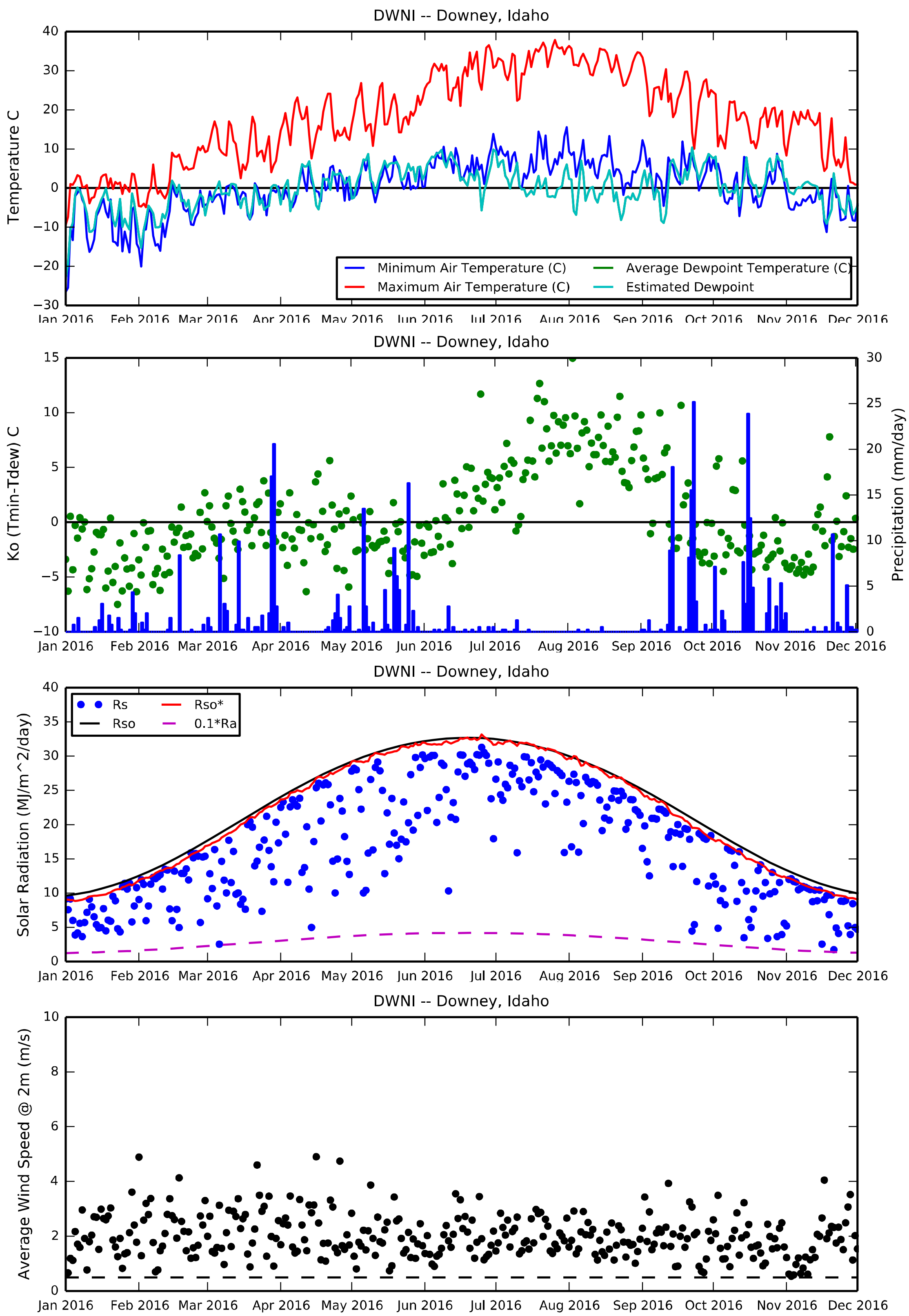


Figure 44. Downey ID (DWNI) meteorological time series (Est.Tdew = Ave.Tdew).

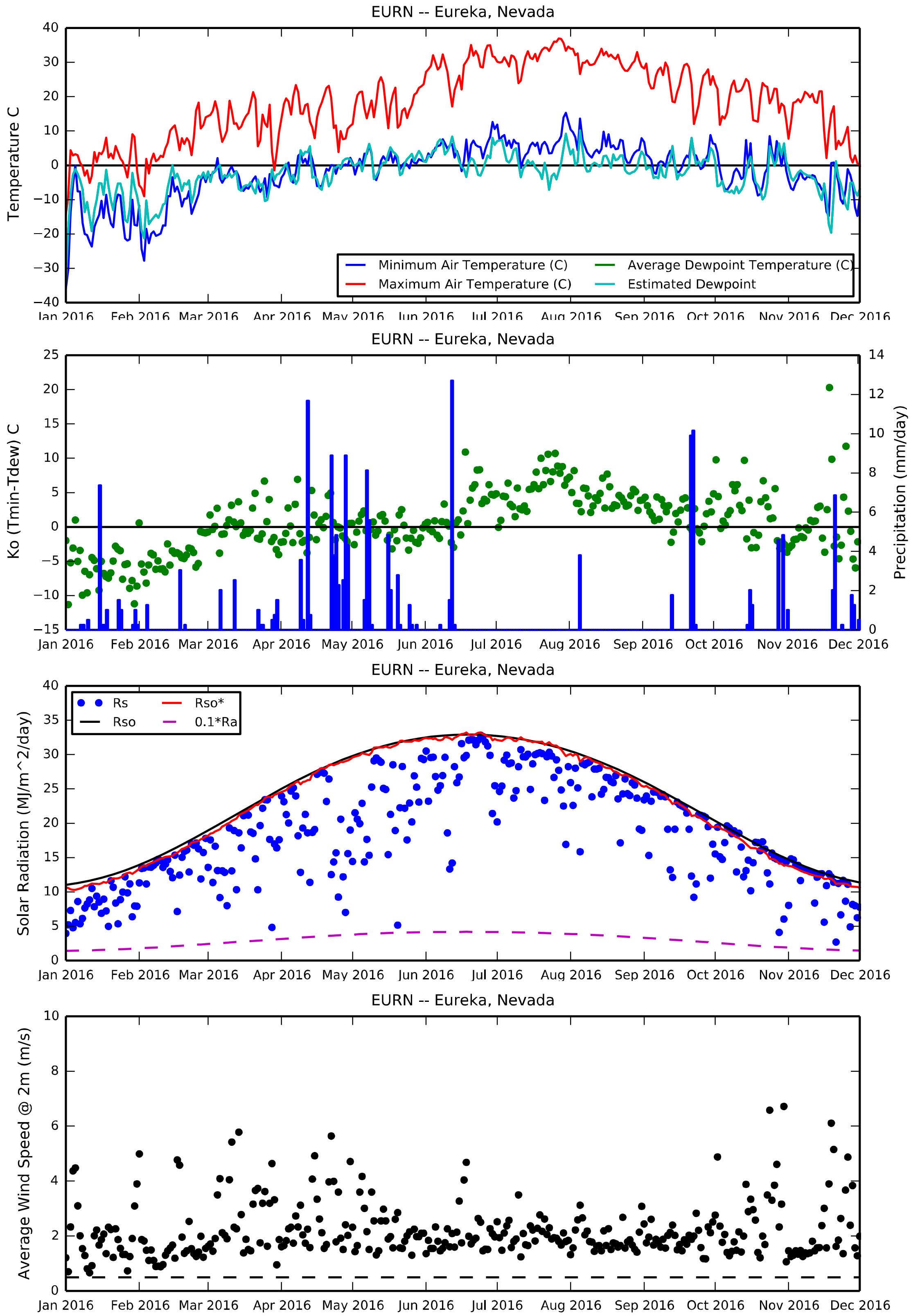


Figure 45. Eureka NV (EURN) meteorological time series (Est.Tdew = Ave.Tdew).

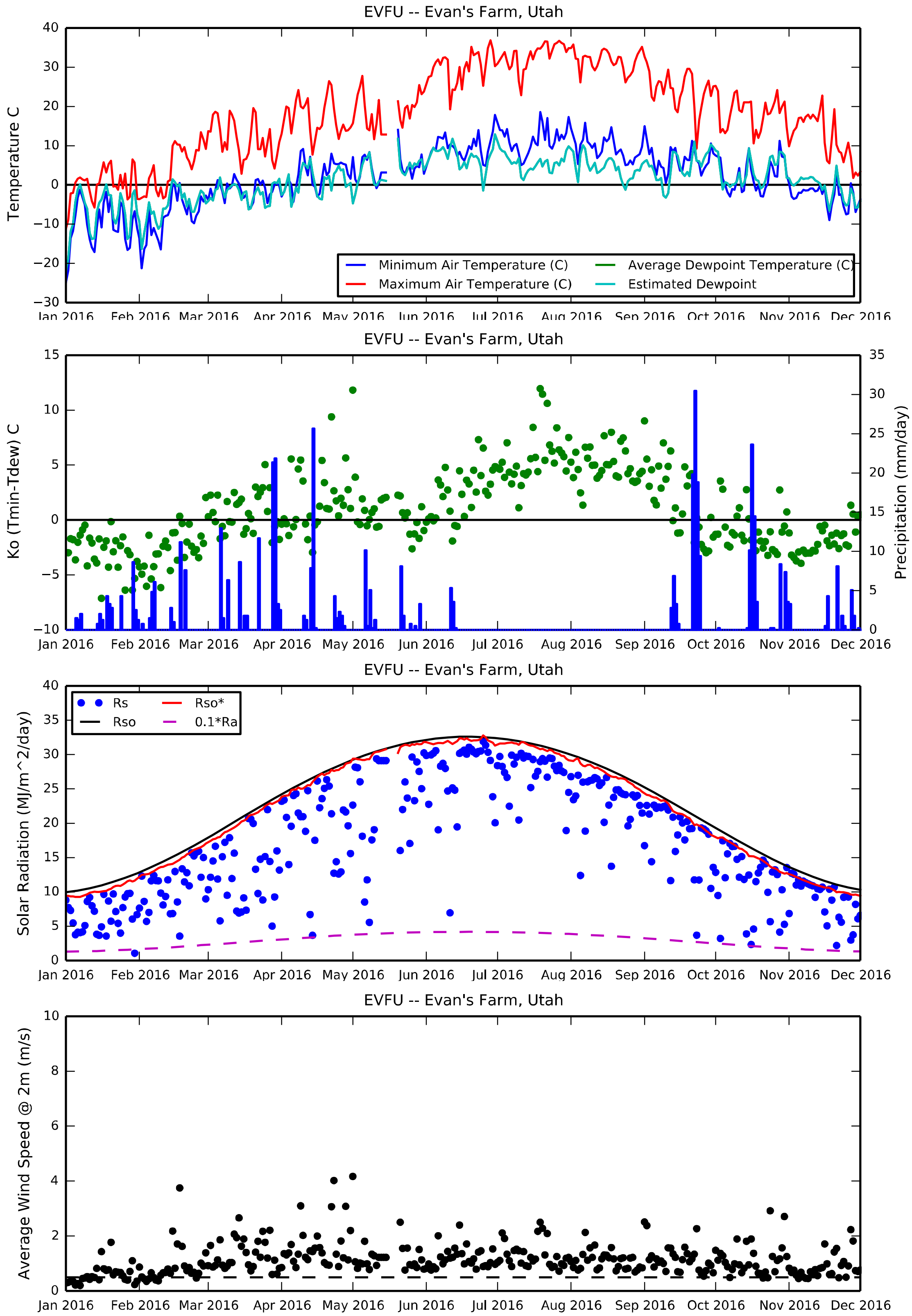


Figure 46. Evans Farm UT (EVFU) meteorological time series (Est.Tdew = Ave.Tdew).

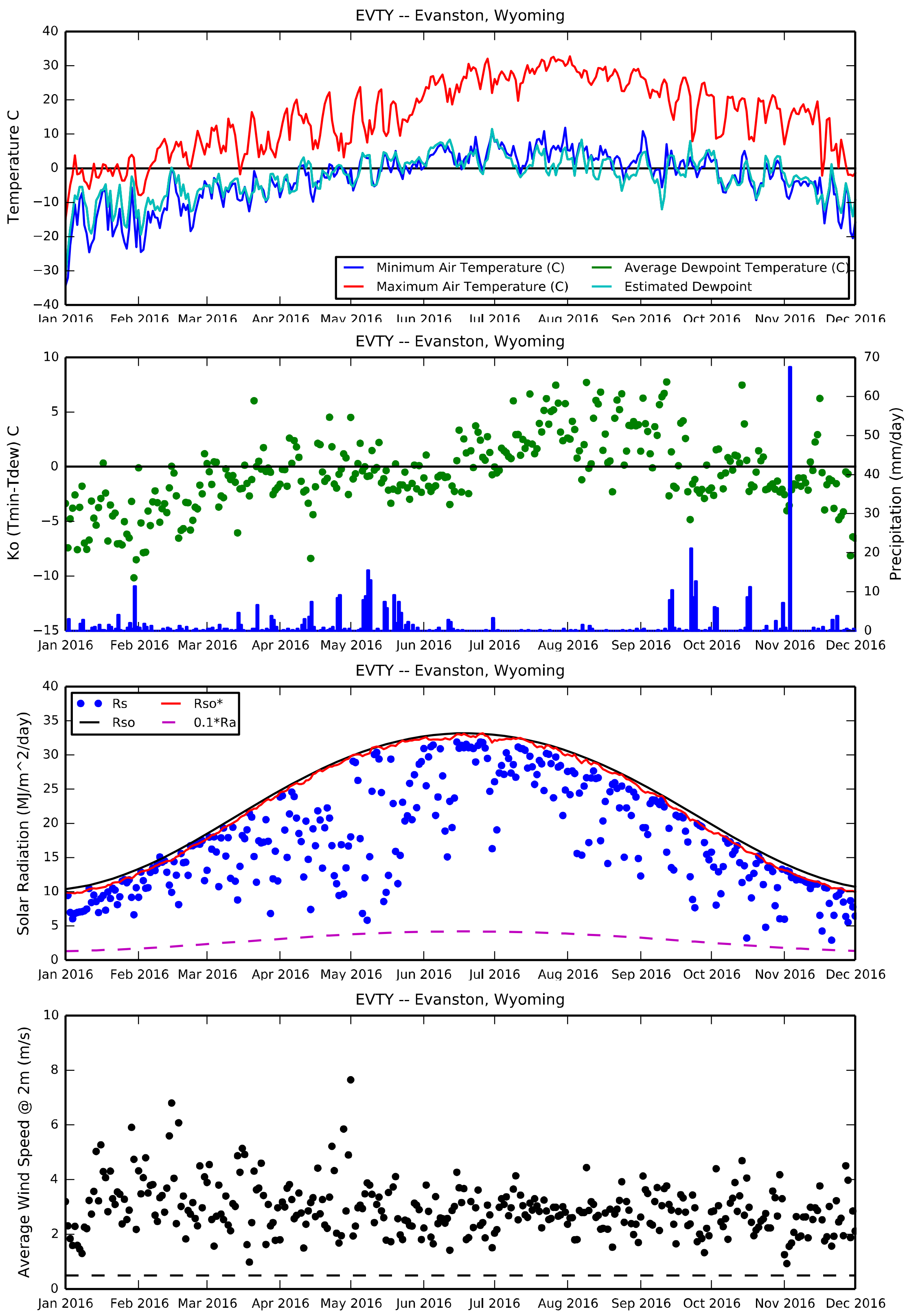


Figure 47. Evanston WY (EVTY) meteorological time series (Est.Tdew = Ave.Tdew).

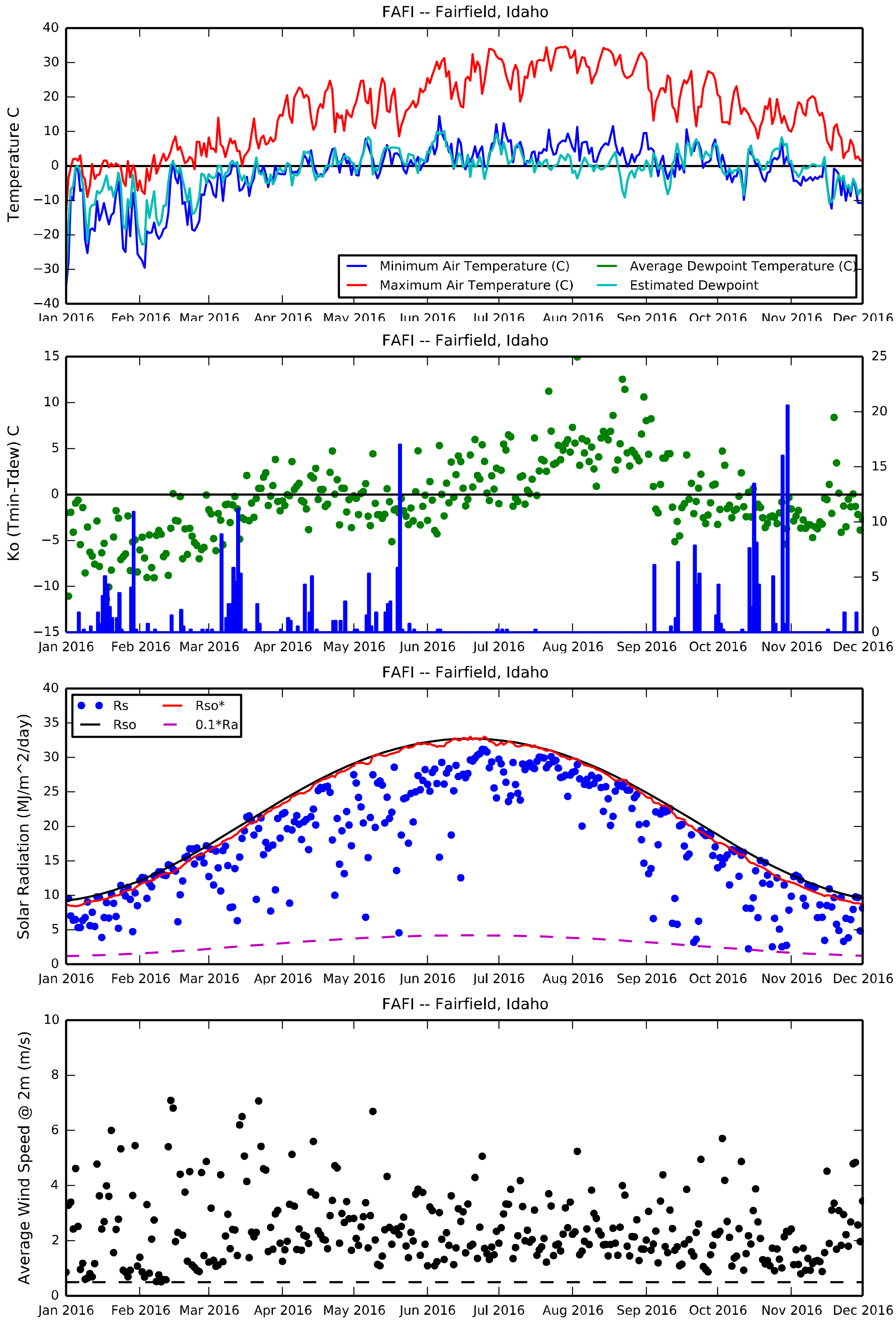


Figure 48. Fairfield ID (FAFI) meteorological time series (Est.Tdew = Ave.Tdew).

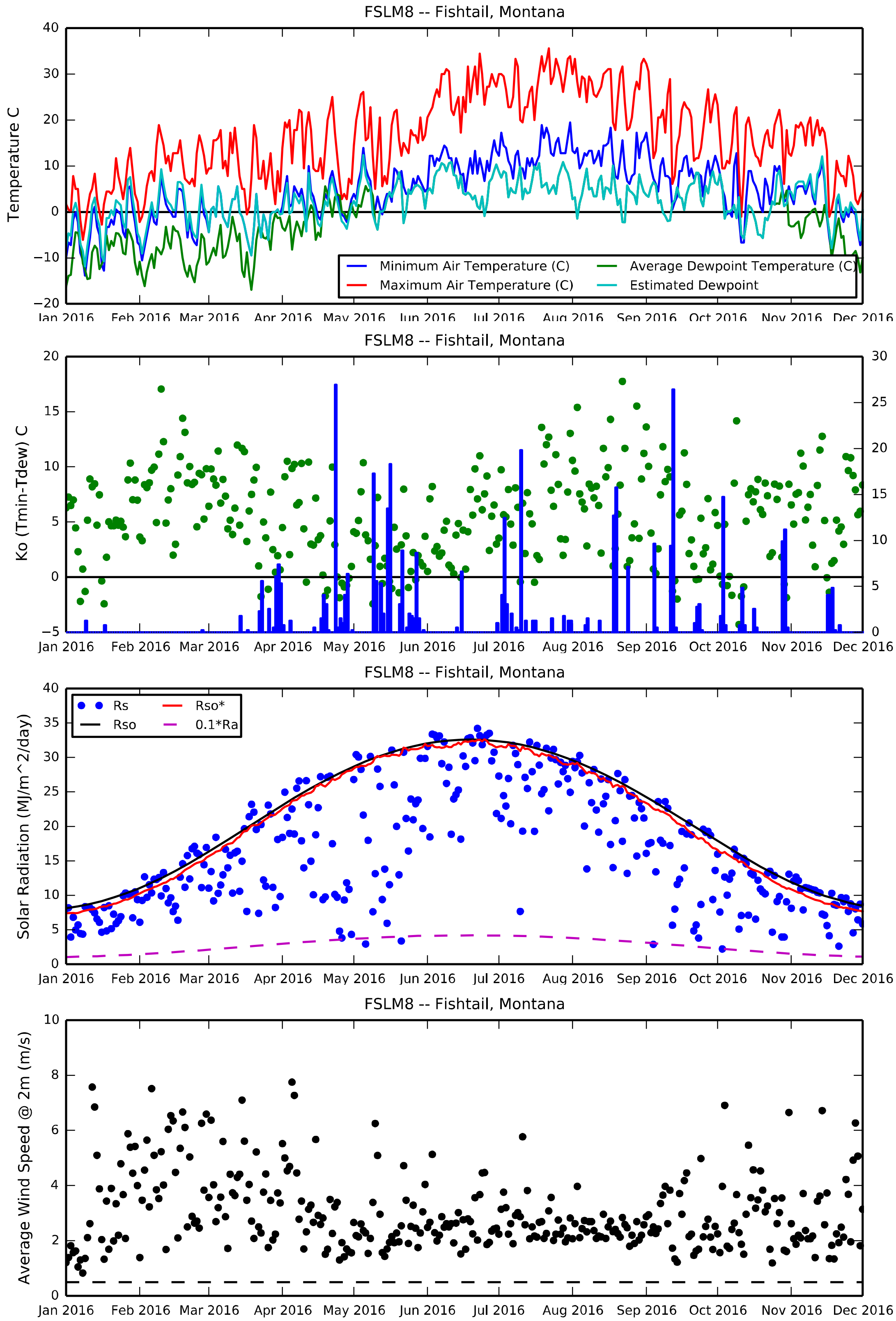


Figure 49. Fishtail MT (FSLM8) meteorological time series (Est.Tdew = f(ETIdaKo, Ave.Tdew)).

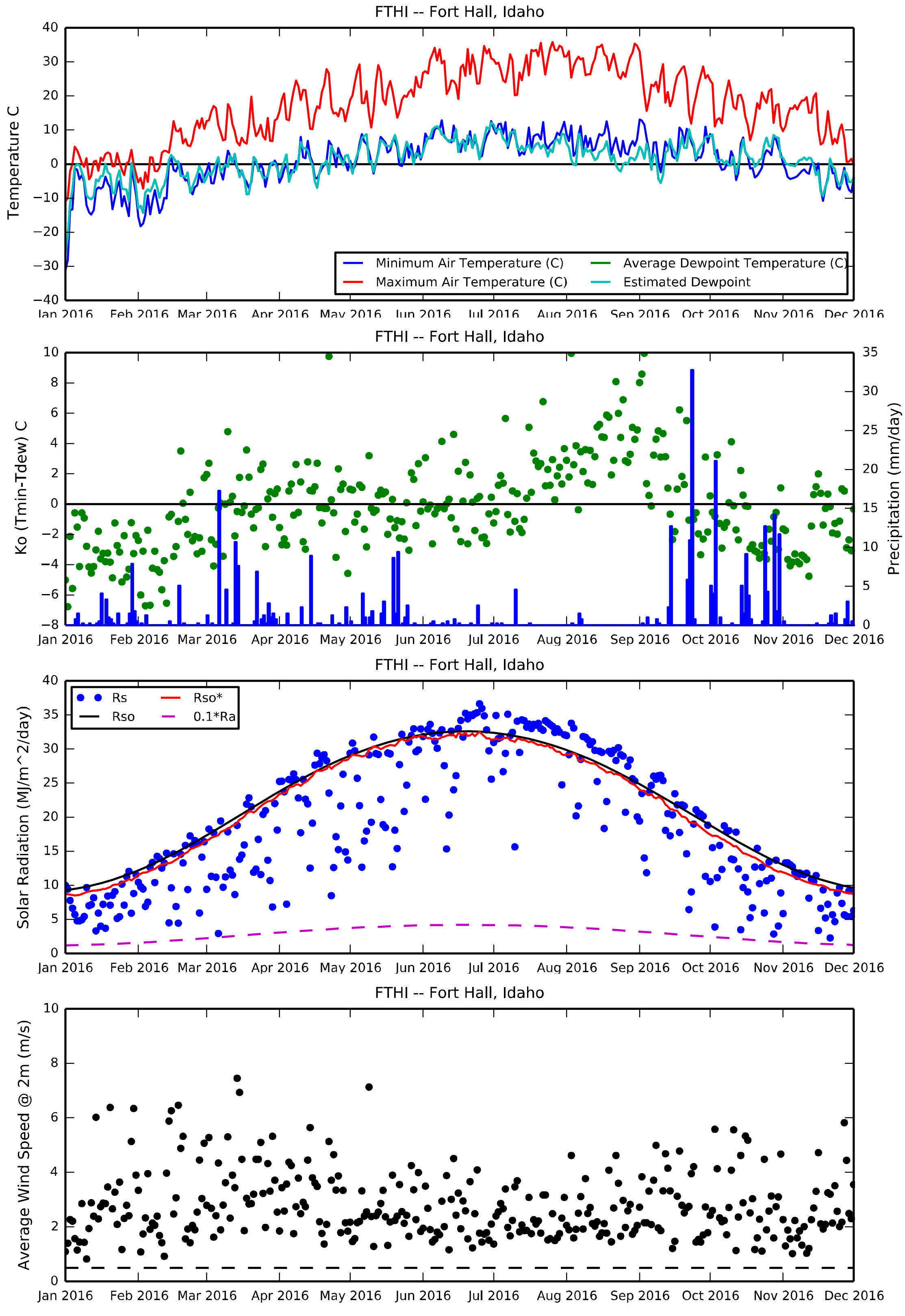


Figure 50. Fort Hall ID (FTHI)) meteorological time series (Est.Tdew = Ave.Tdew).

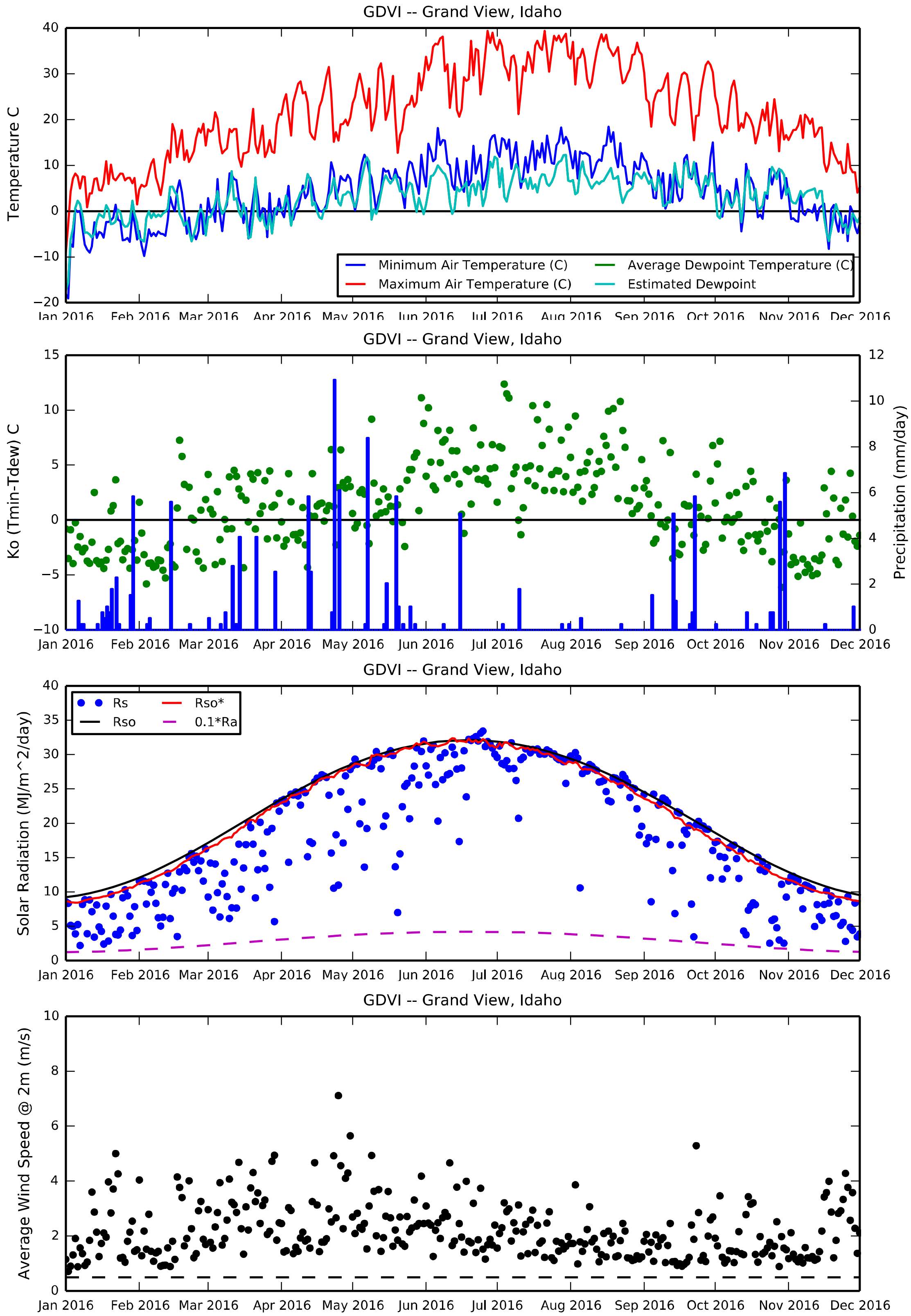


Figure 51. Grandview ID (GDVI) meteorological time series (Est.Tdew = Ave.Tdew).

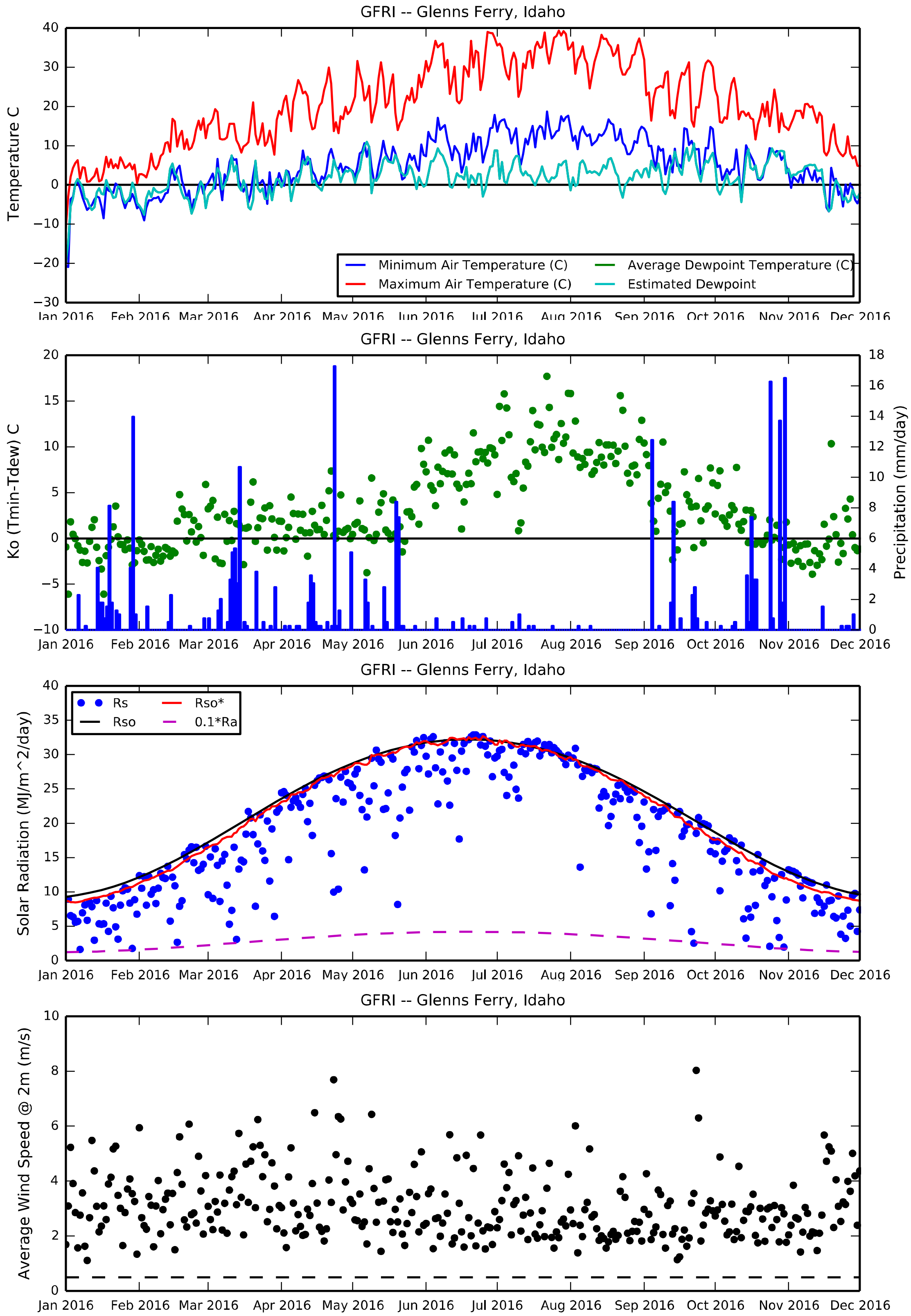


Figure 52. Glenns Ferry ID (GFRI) meteorological time series (Est.Tdew = Ave.Tdew).

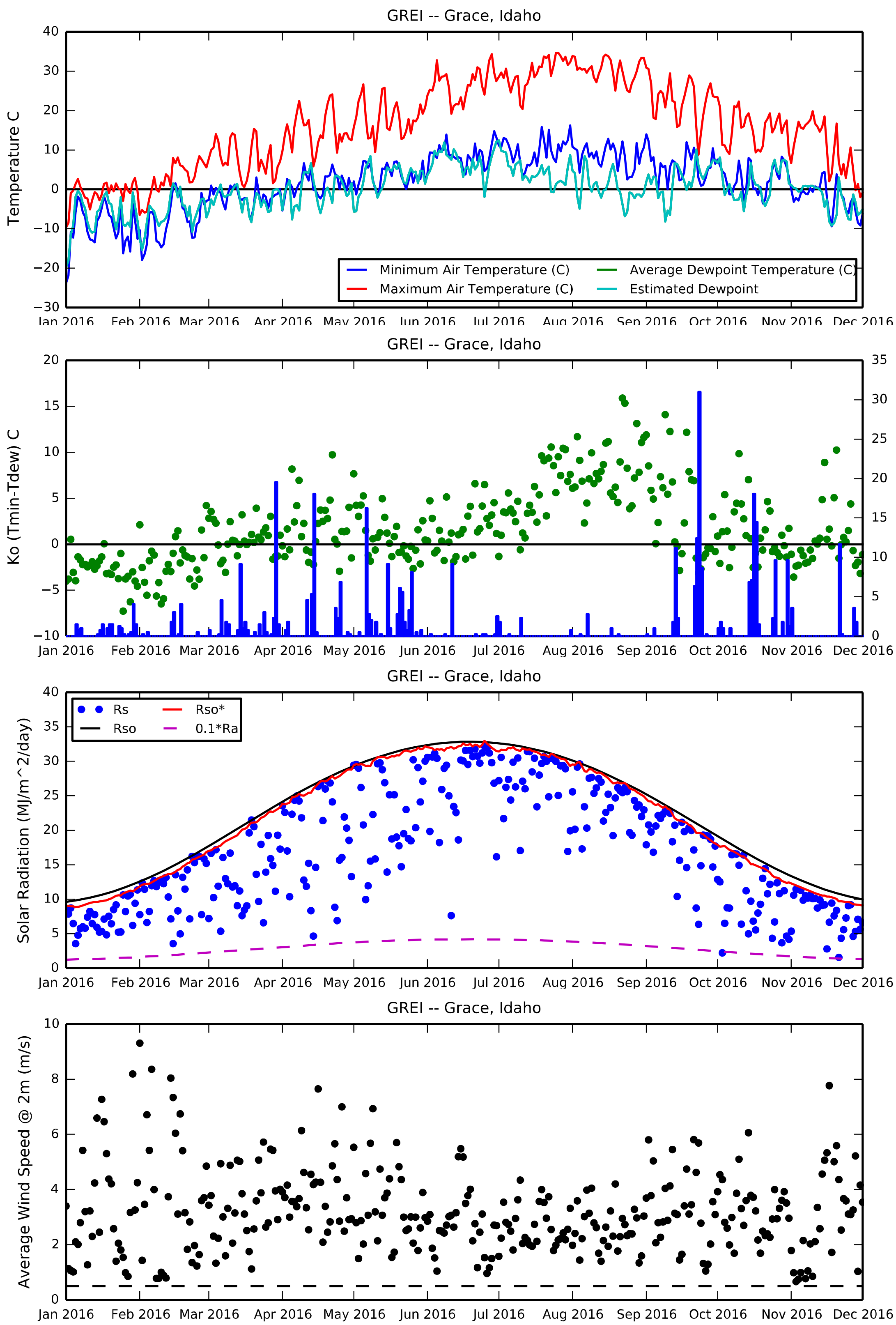


Figure 53. Grace ID (GREI) meteorological time series (Est.Tdew = Ave.Tdew).

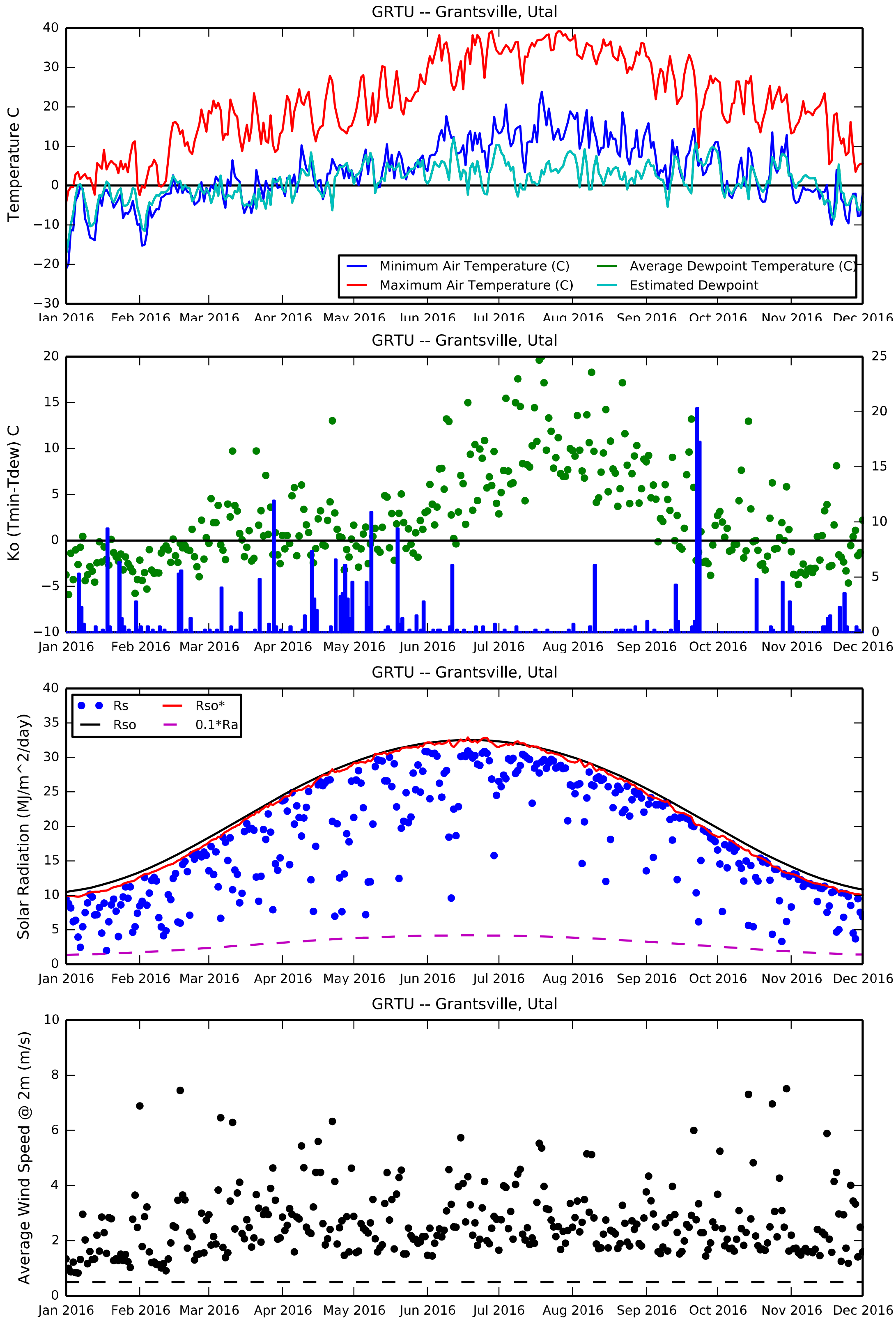


Figure 54. Grantsville UT (GRTU) meteorological time series (Est.Tdew = Ave.Tdew).

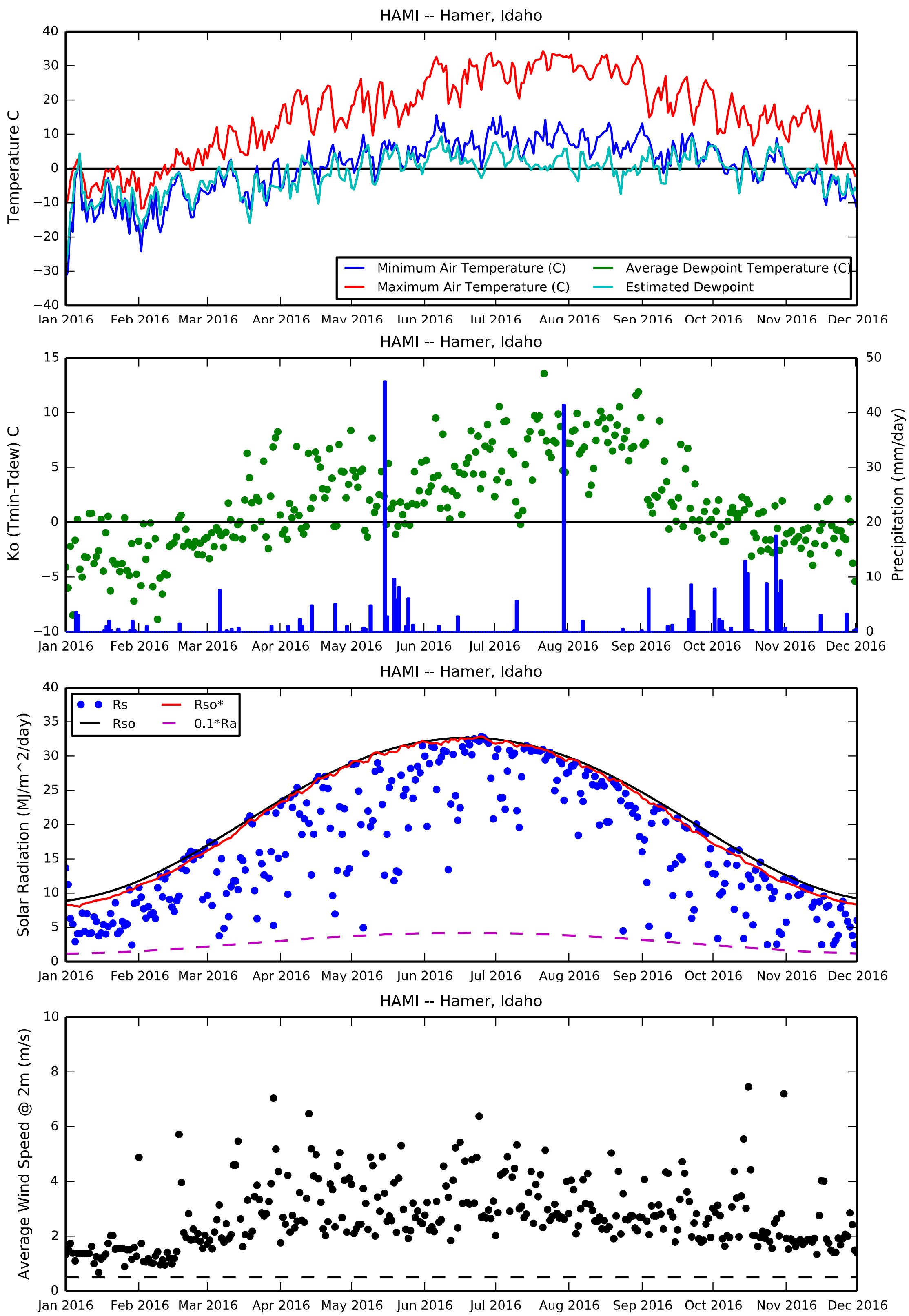


Figure 55. Hamer ID (HAMI) meteorological time series (Est.Tdew = Ave.Tdew).

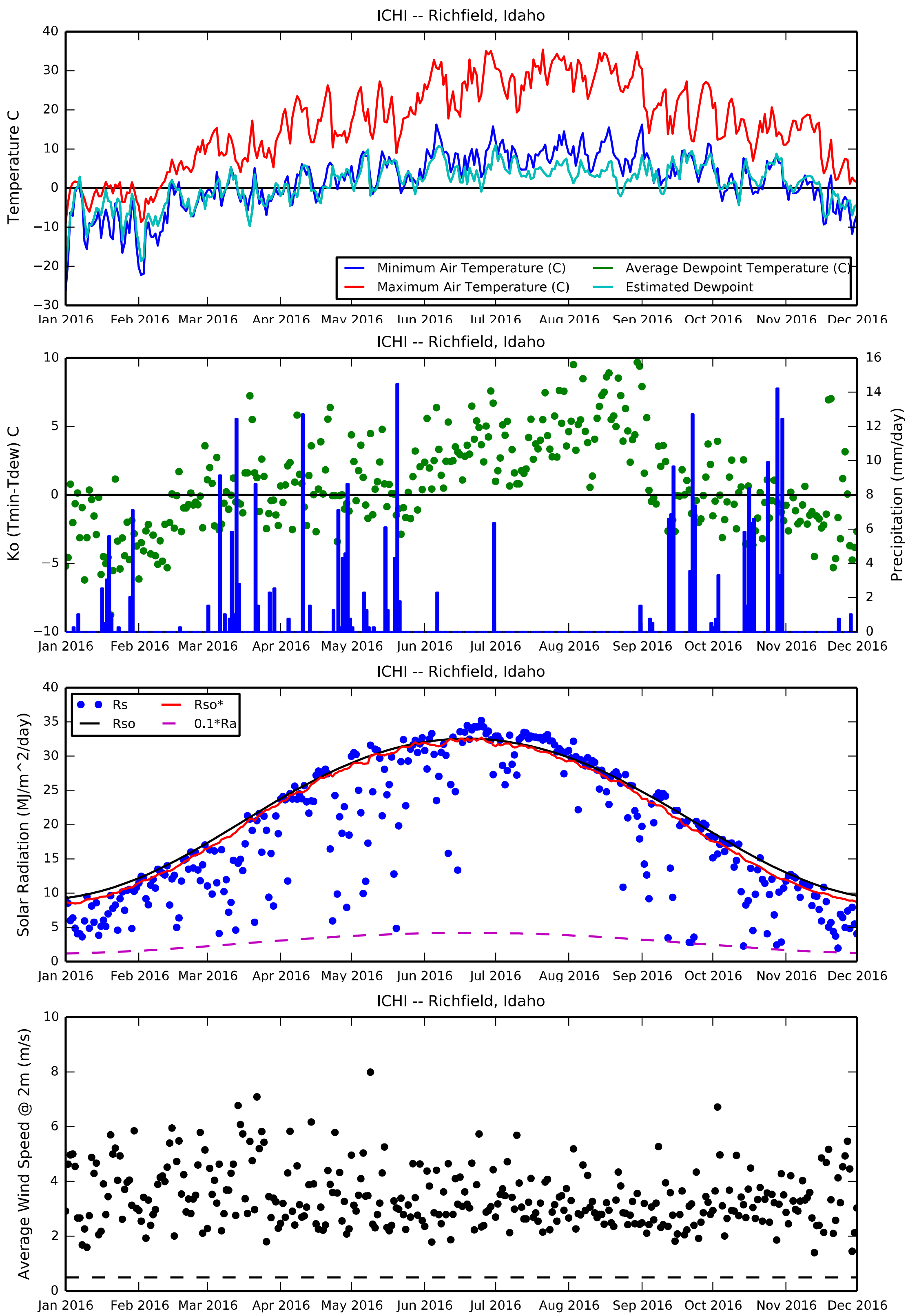


Figure 56. Richfield ID (ICHI) meteorological time series (Est.Tdew = Ave.Tdew).

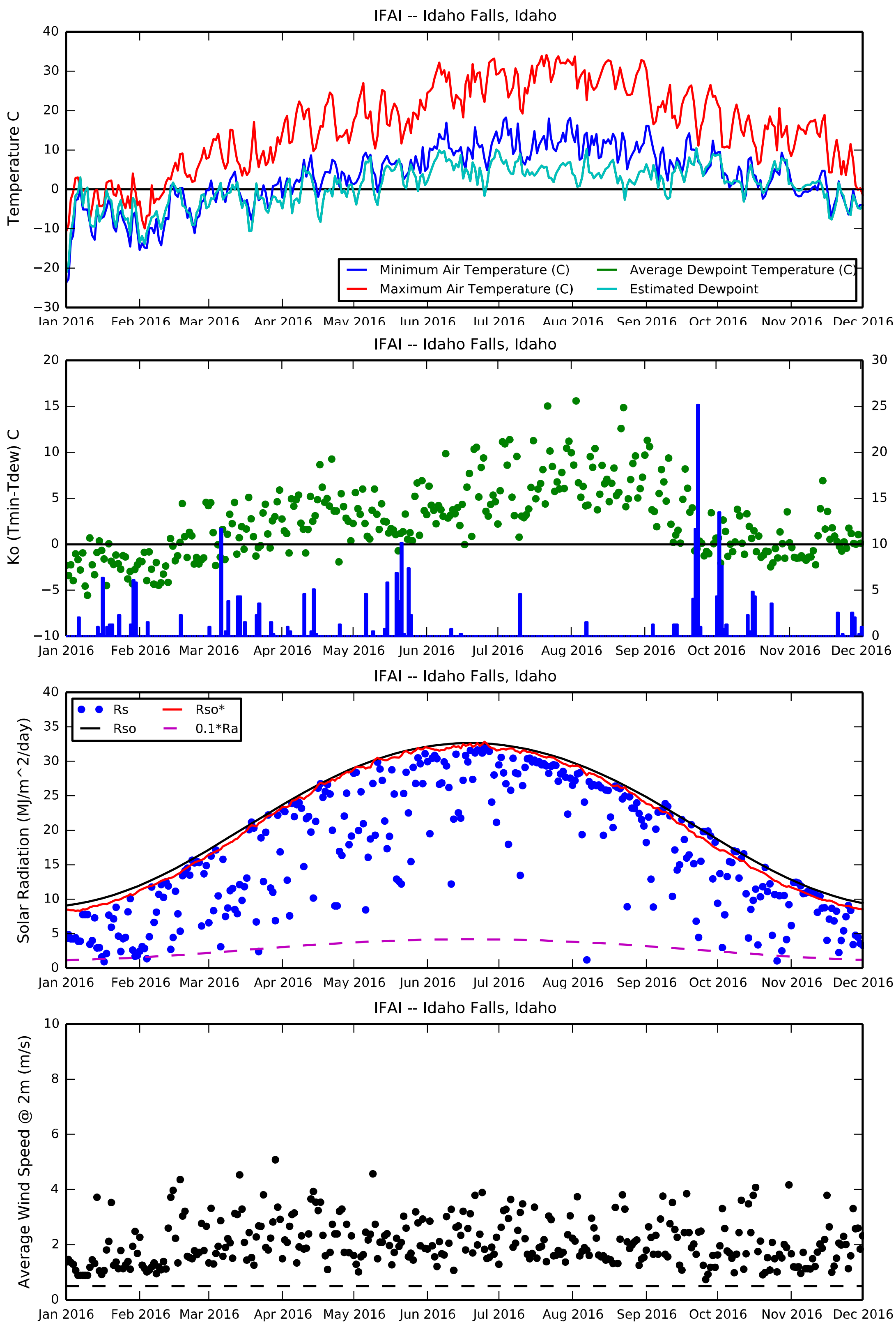


Figure 57. Idaho Falls ID (IFAI) meteorological time series (Est.Tdew = Ave.Tdew).

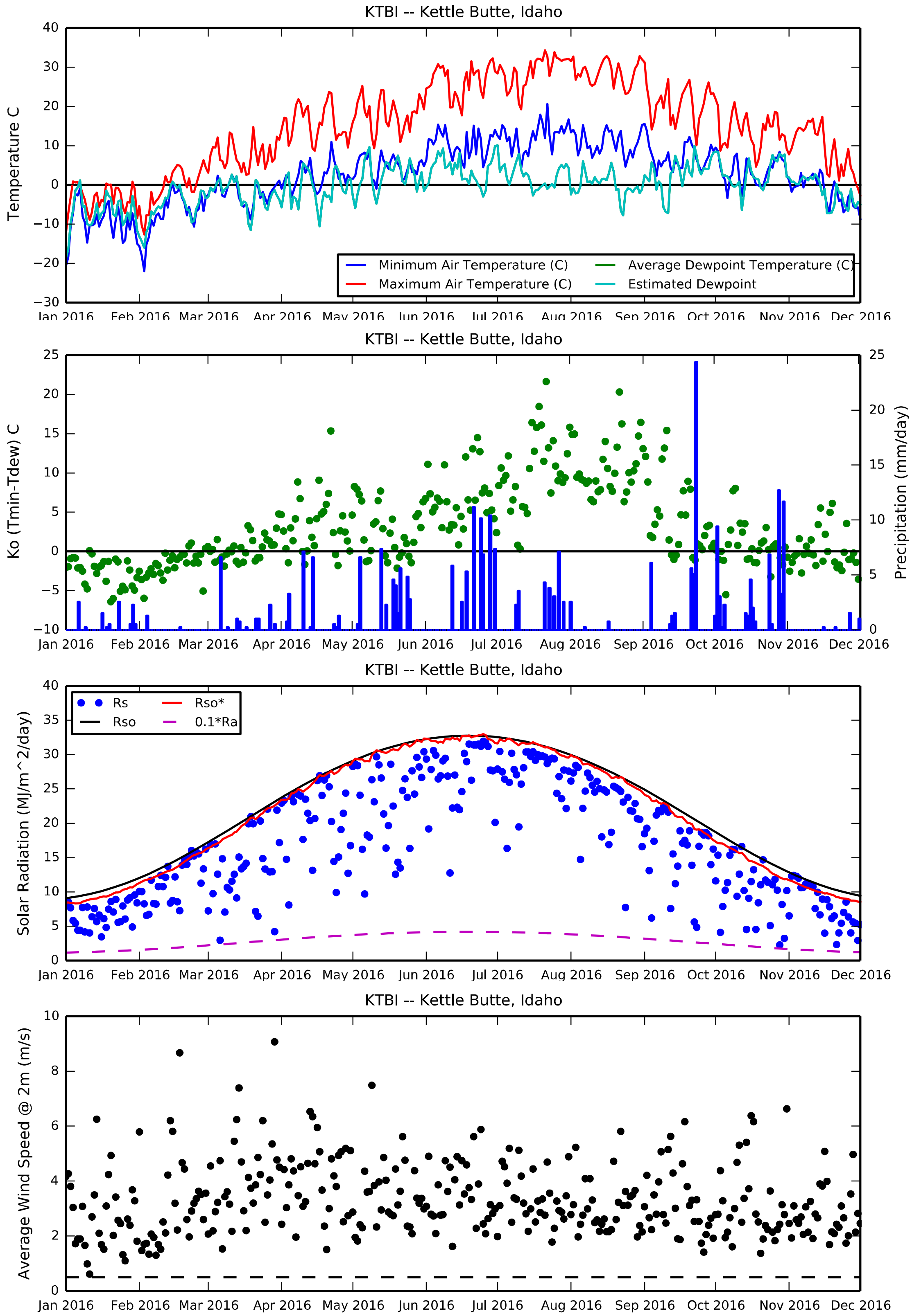


Figure 58. Kettle Butte ID (KTBI) meteorological time series (Est.Tdew = Ave.Tdew).

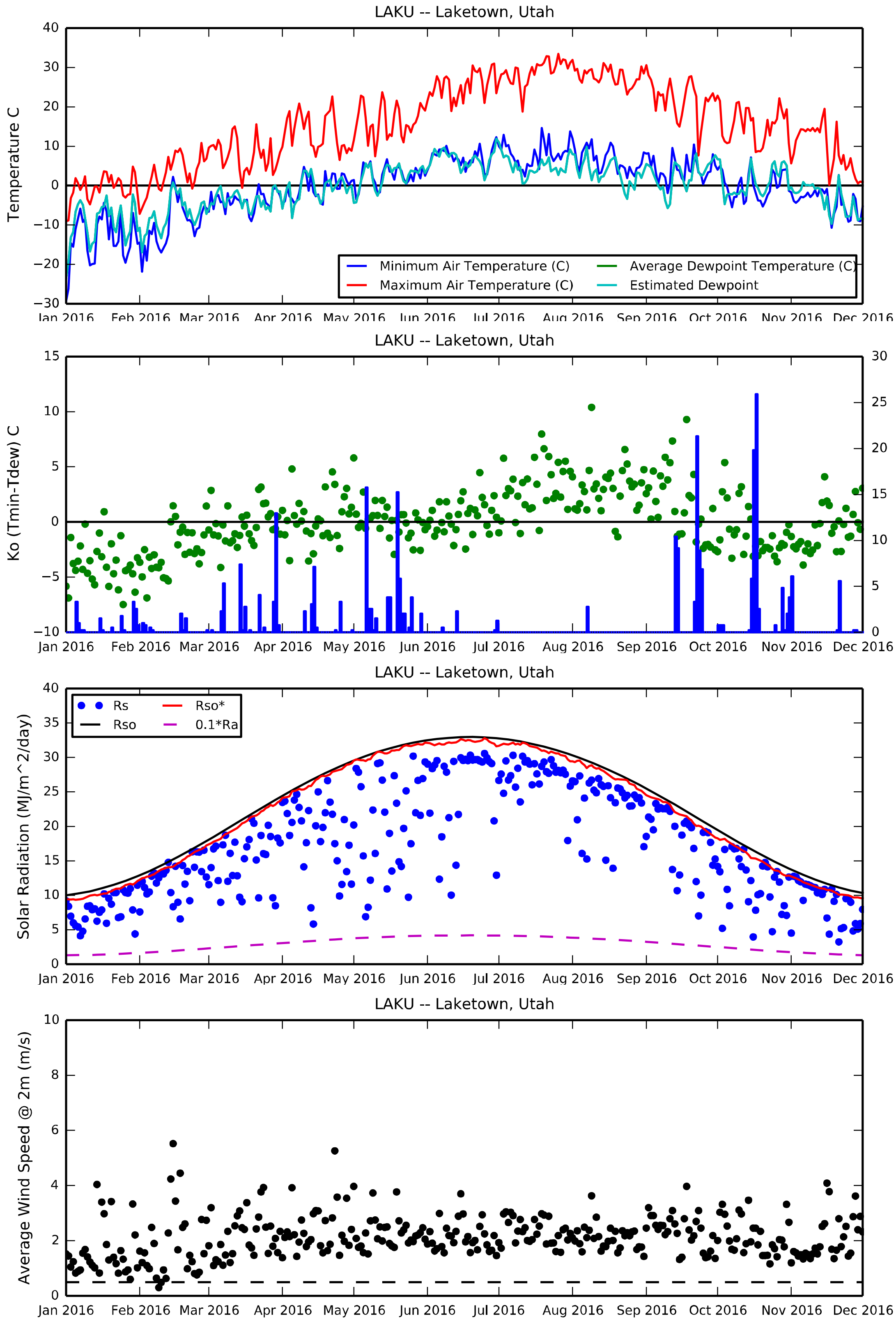


Figure 59. Laketown UT (LAKU) meteorological time series (Est.Tdew = Ave.Tdew).

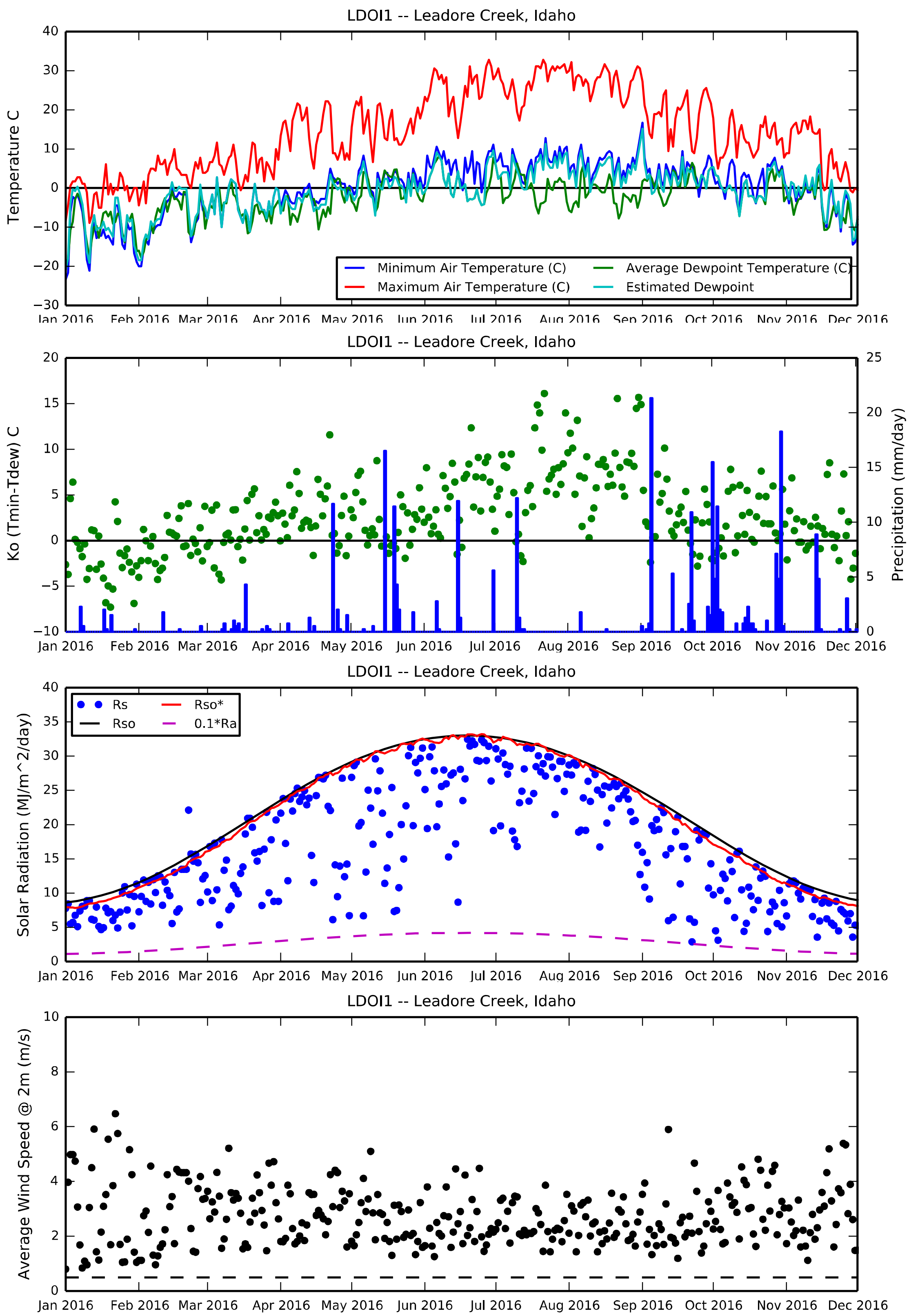


Figure 60. Leadore Creek ID (LDOI1) meteorological time series (Est.Tdew = f(ETidaKo, Ave.Tdew)).

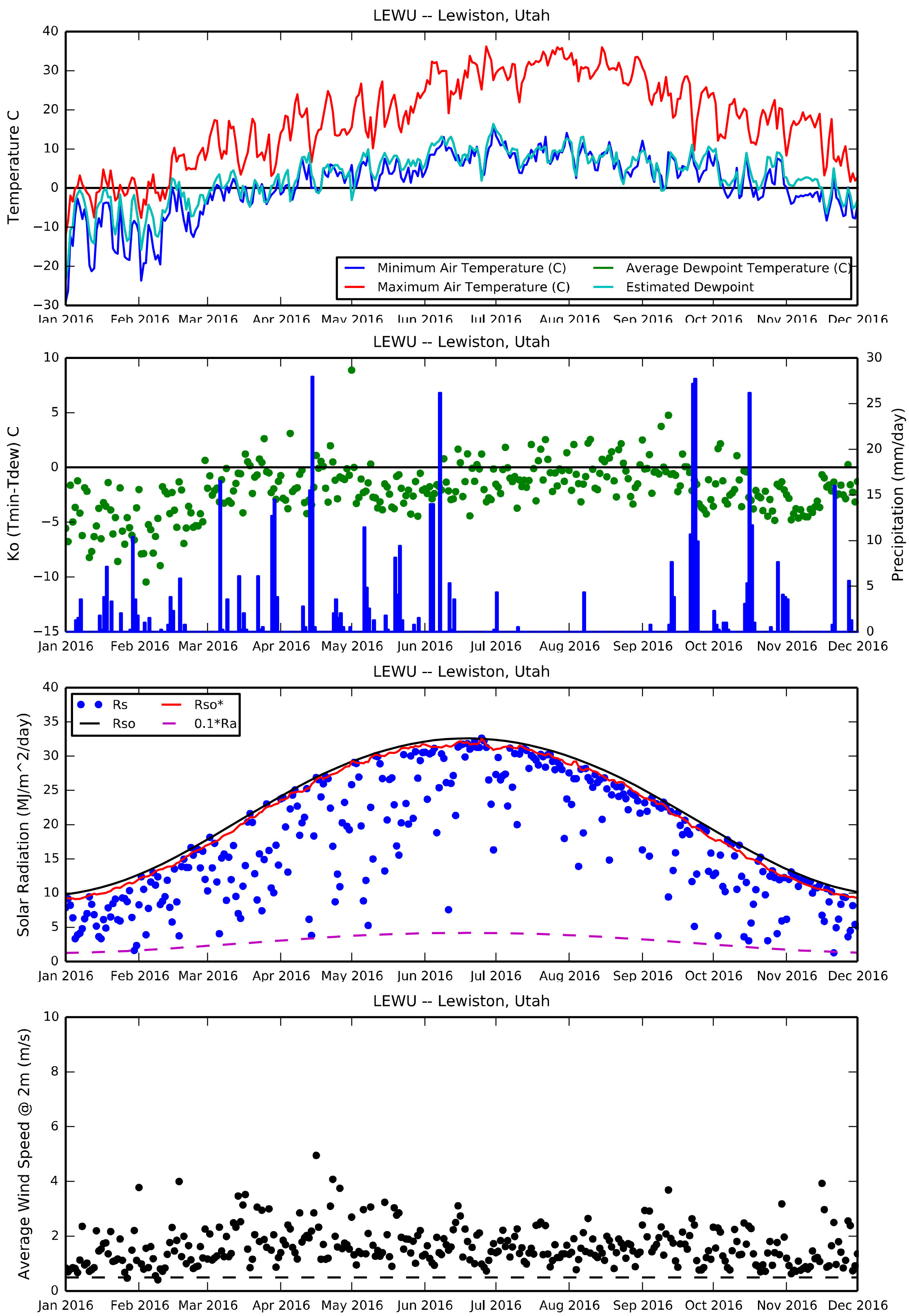


Figure 61. Lewiston UT (LEWU) meteorological time series (Est.Tdew = Ave.Tdew).

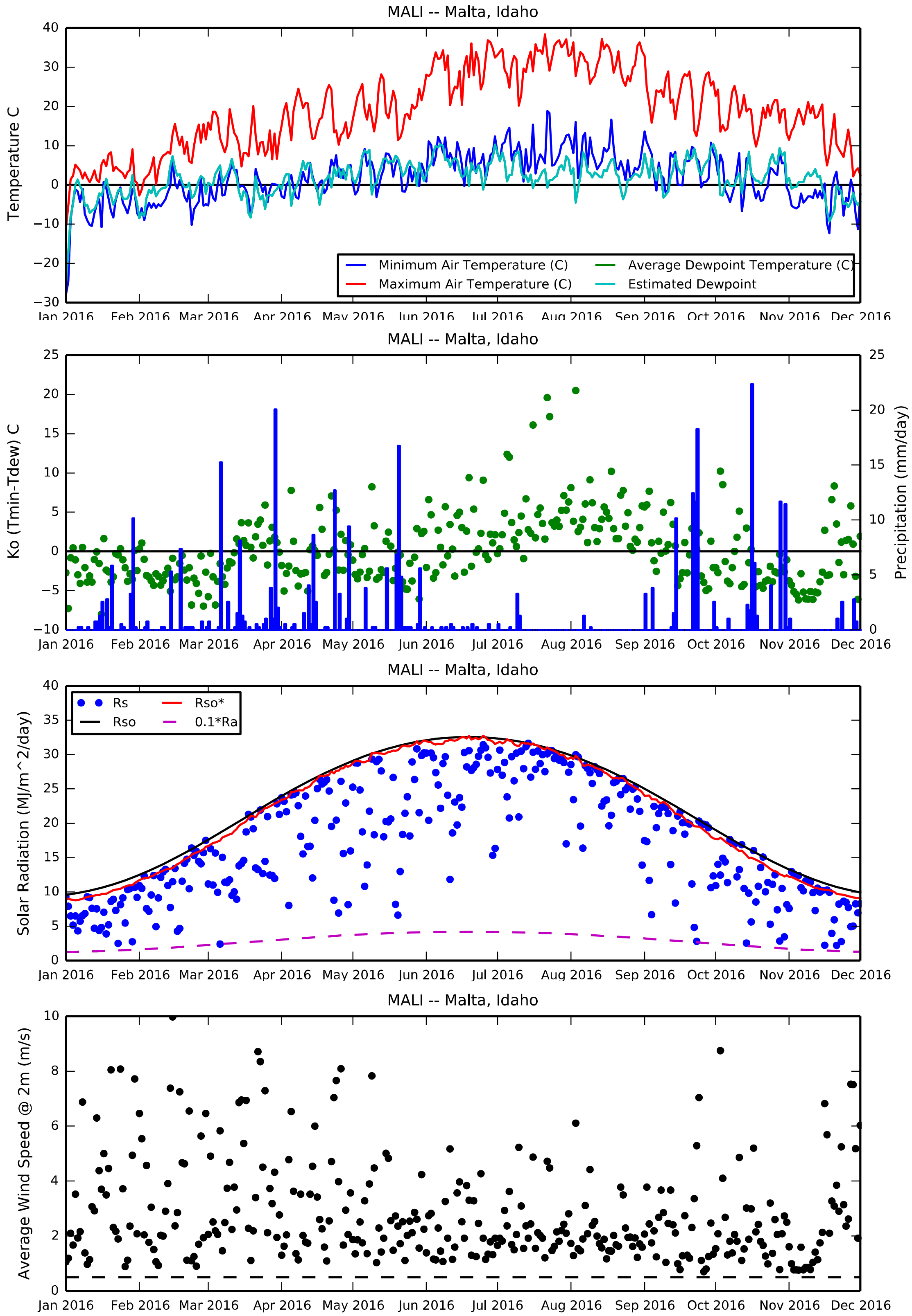


Figure 62. Malta ID (MALI) meteorological time series (Est.Tdew = Ave.Tdew).

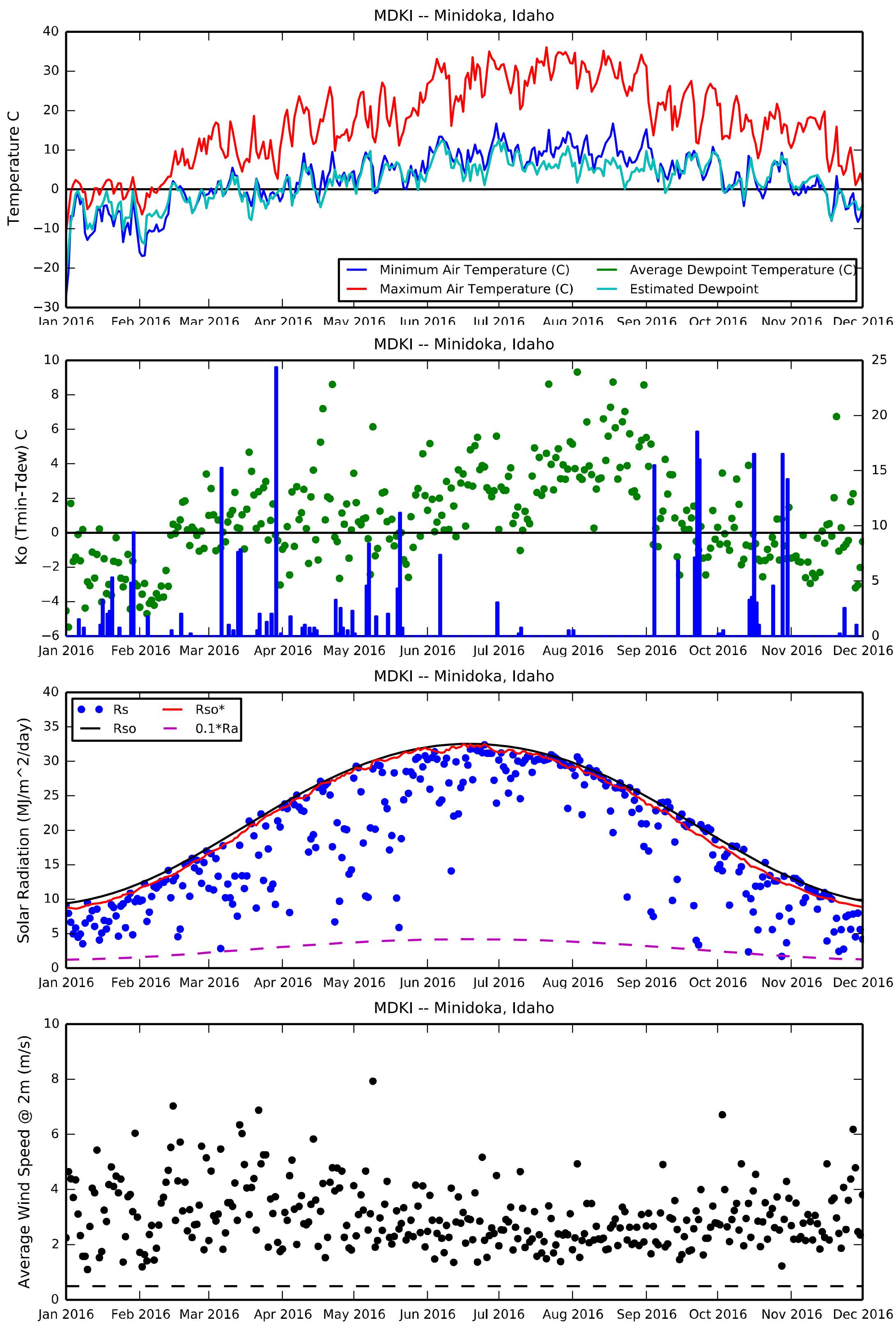


Figure 63. Minidoka ID (MDKI) meteorological time series (Est.Tdew = Ave.Tdew).

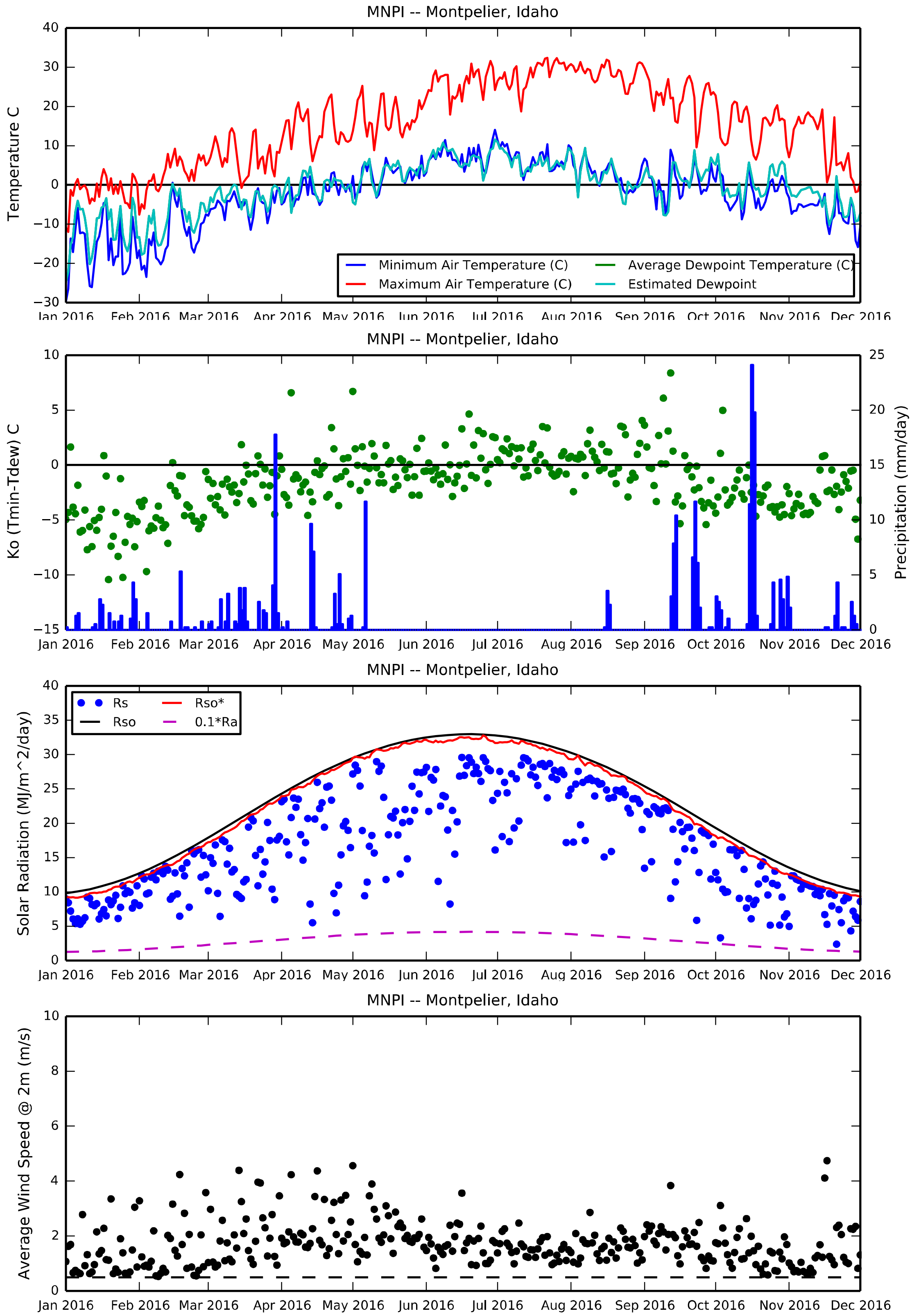


Figure 64. Montpelier ID (MNPI) meteorological time series (Est.Tdew = Ave.Tdew).

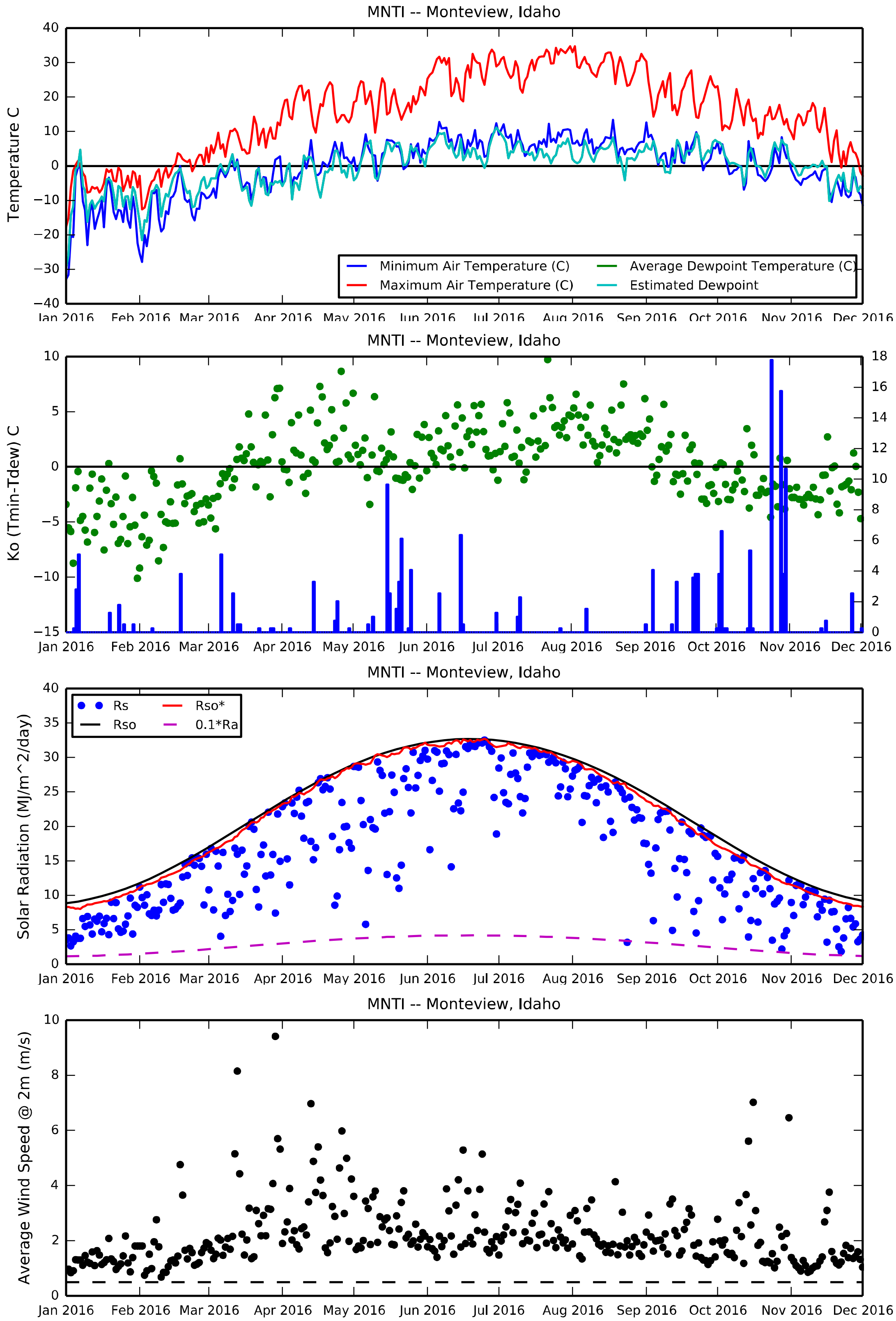


Figure 65. Monteview ID (MNTI) meteorological time series (Est.Tdew = Ave.Tdew).

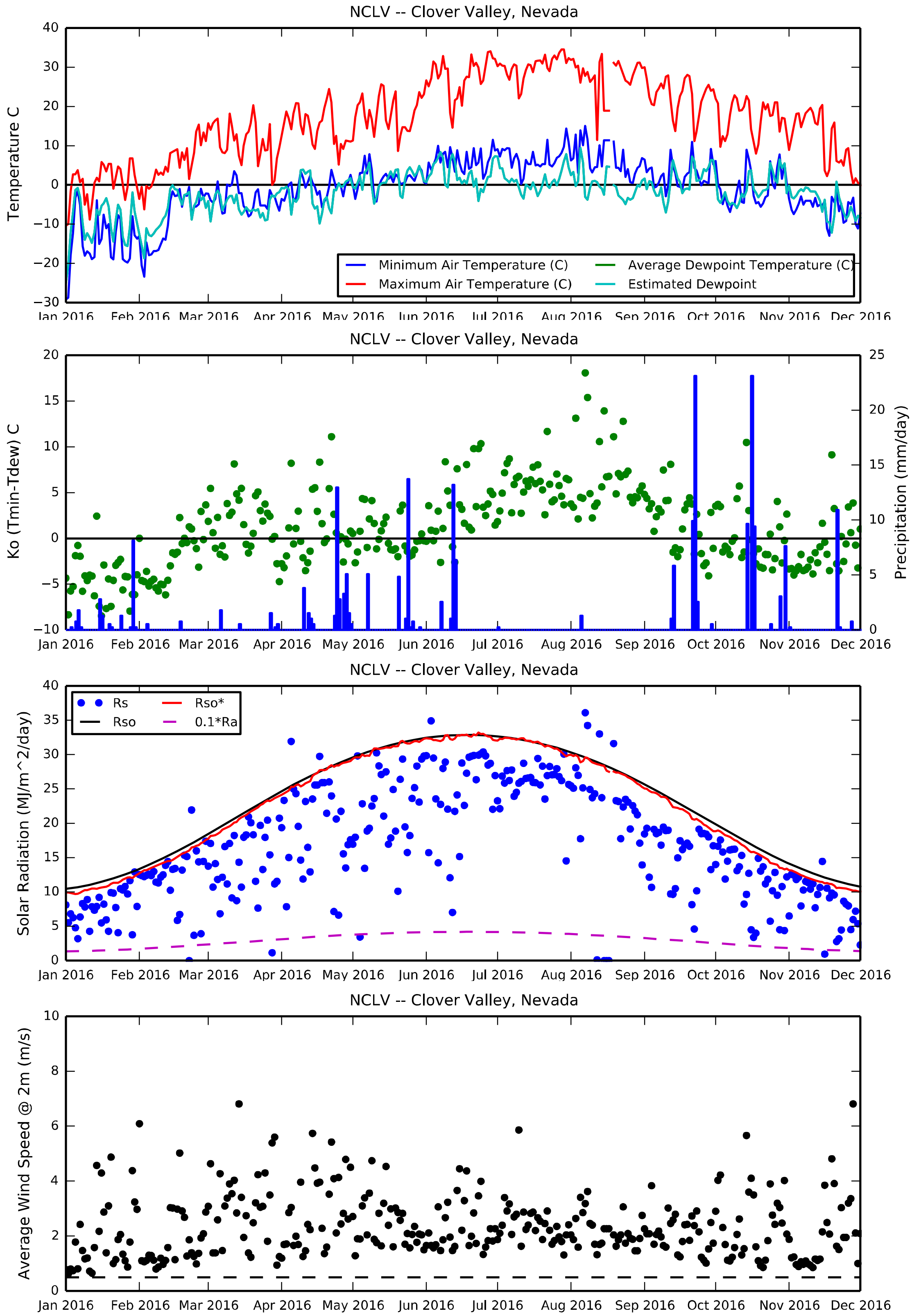


Figure 66. Clover Valley NV (NCLV) meteorological time series (Est.Tdew = Ave.Tdew).

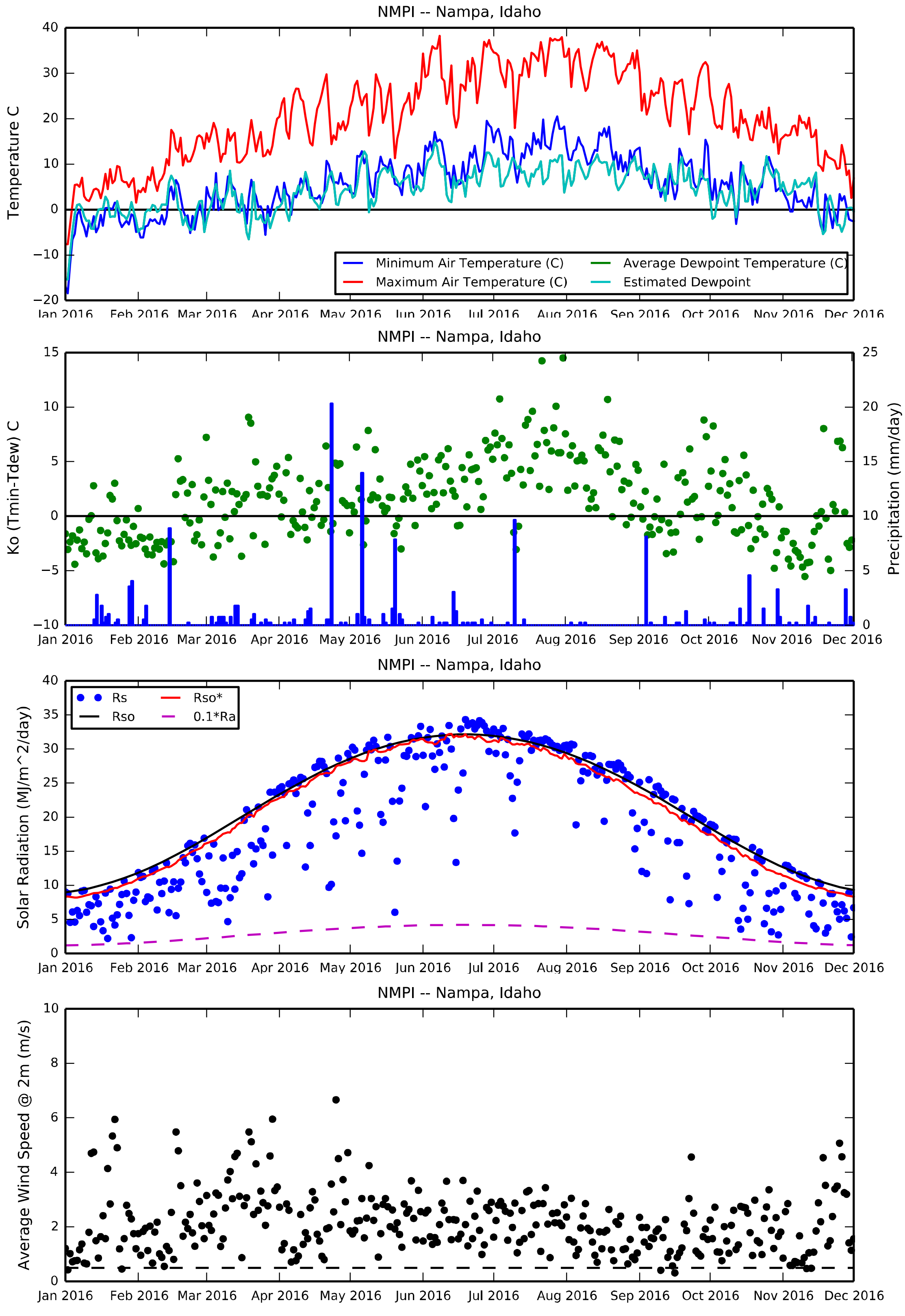


Figure 67. Nampa ID (NMPI) meteorological time series (Est.Tdew = Ave.Tdew).

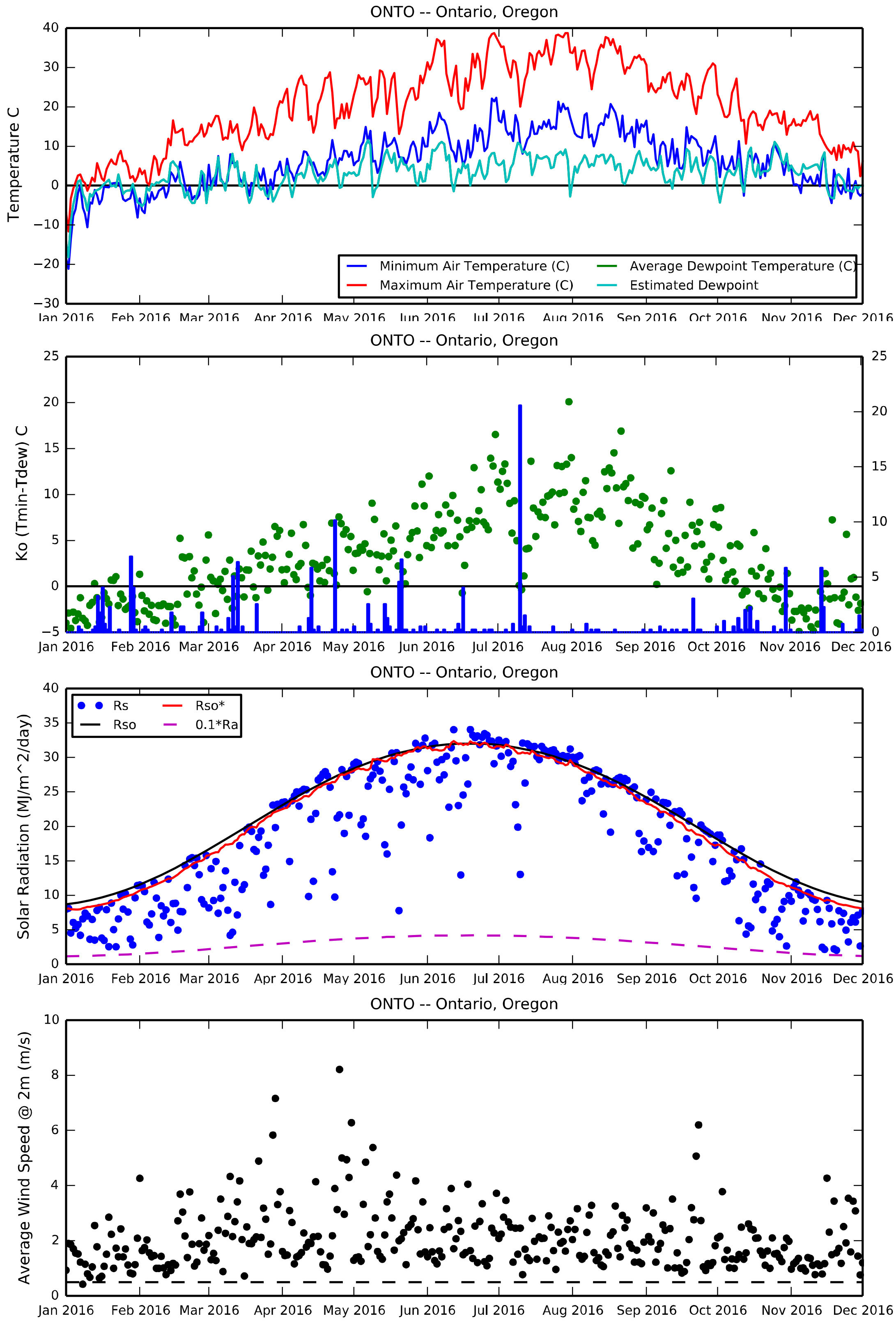


Figure 68. Ontario OR (ONTO) meteorological time series (Est.Tdew = Ave.Tdew).

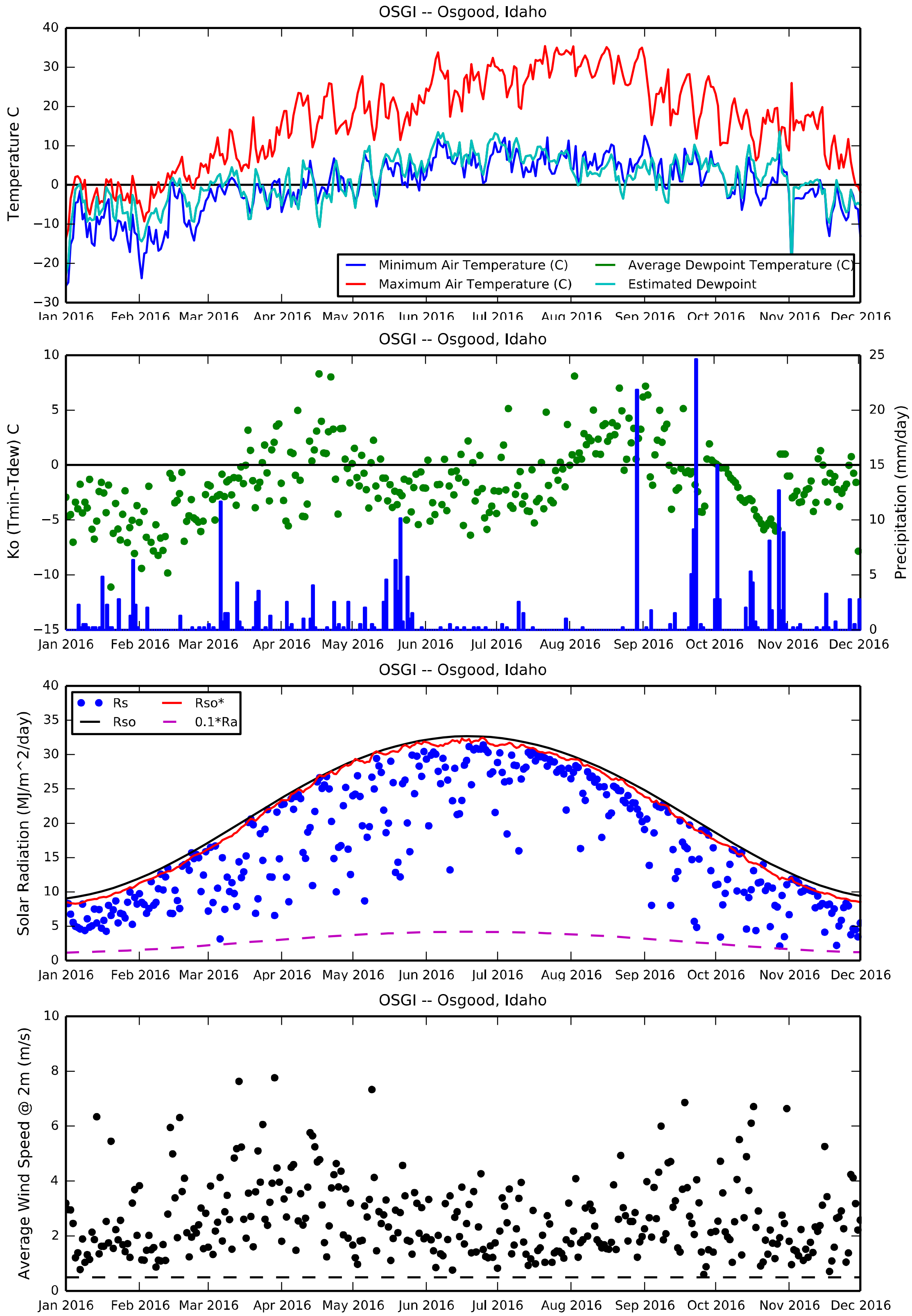


Figure 69. Osgood ID (OSGI) meteorological time series (Est.Tdew = Ave.Tdew).

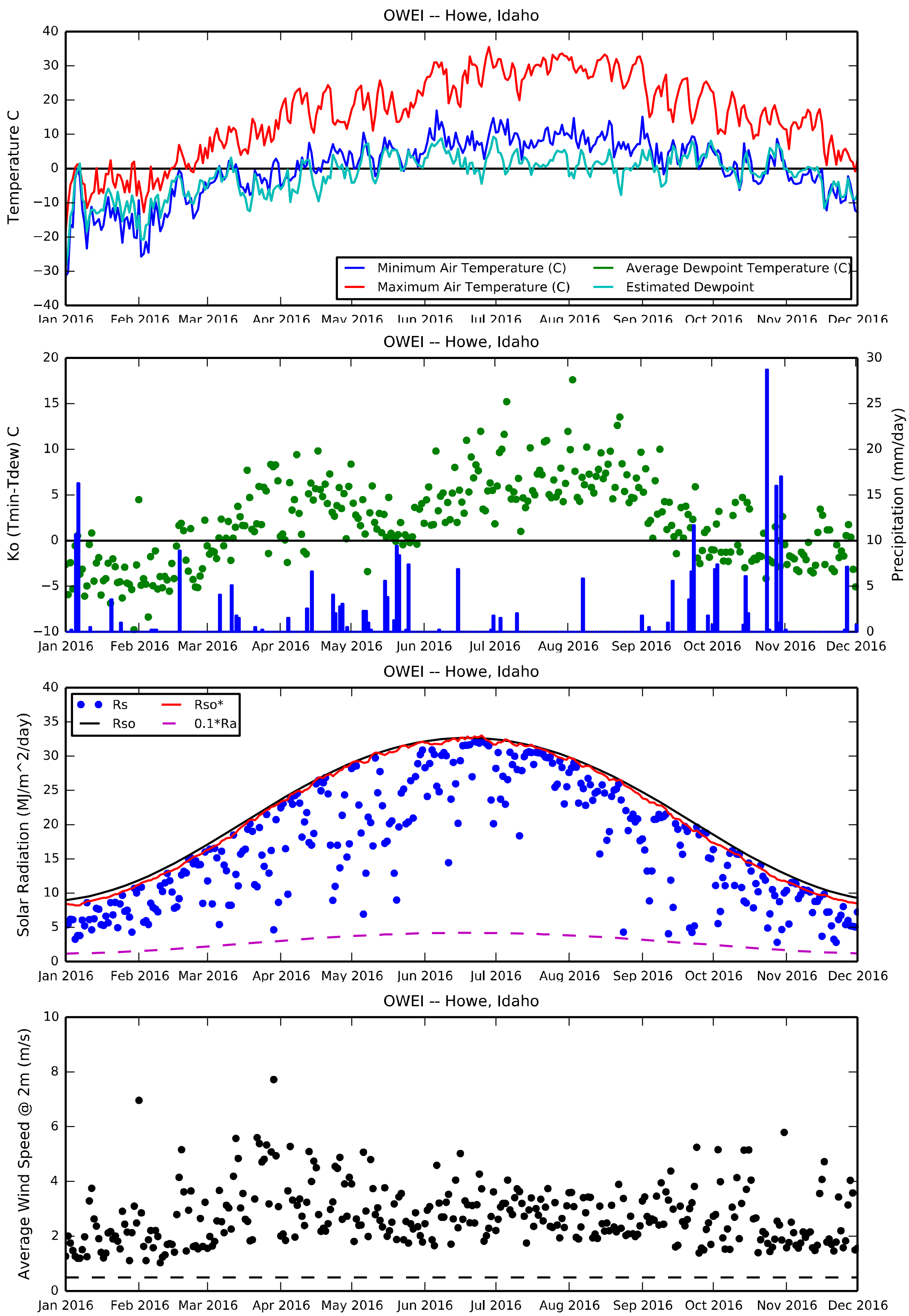


Figure 70. Howe ID (OWEI) meteorological time series (Est.Tdew = Ave.Tdew).

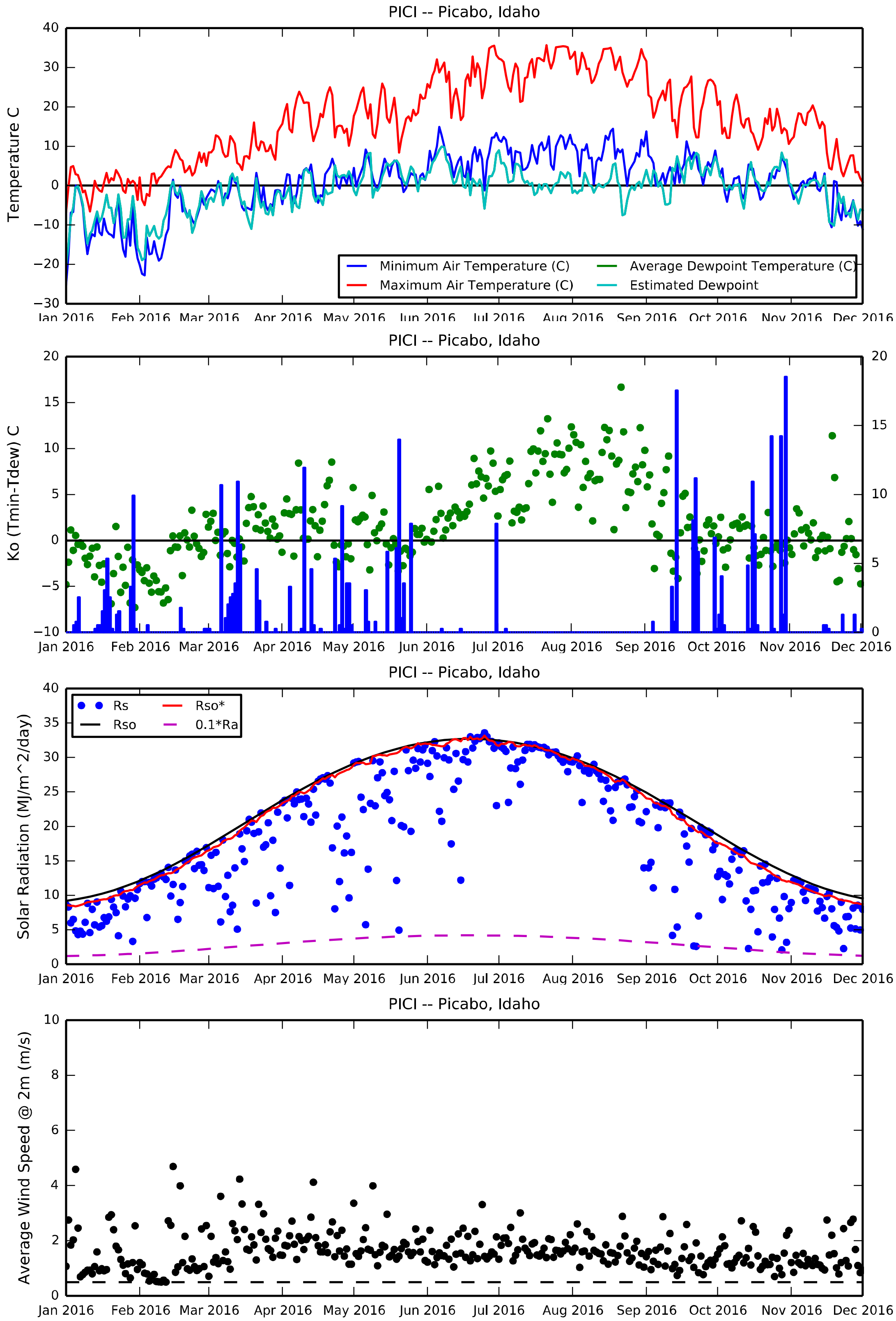


Figure 71. Picabo ID (PICI) meteorological time series (Est.Tdew = Ave.Tdew).

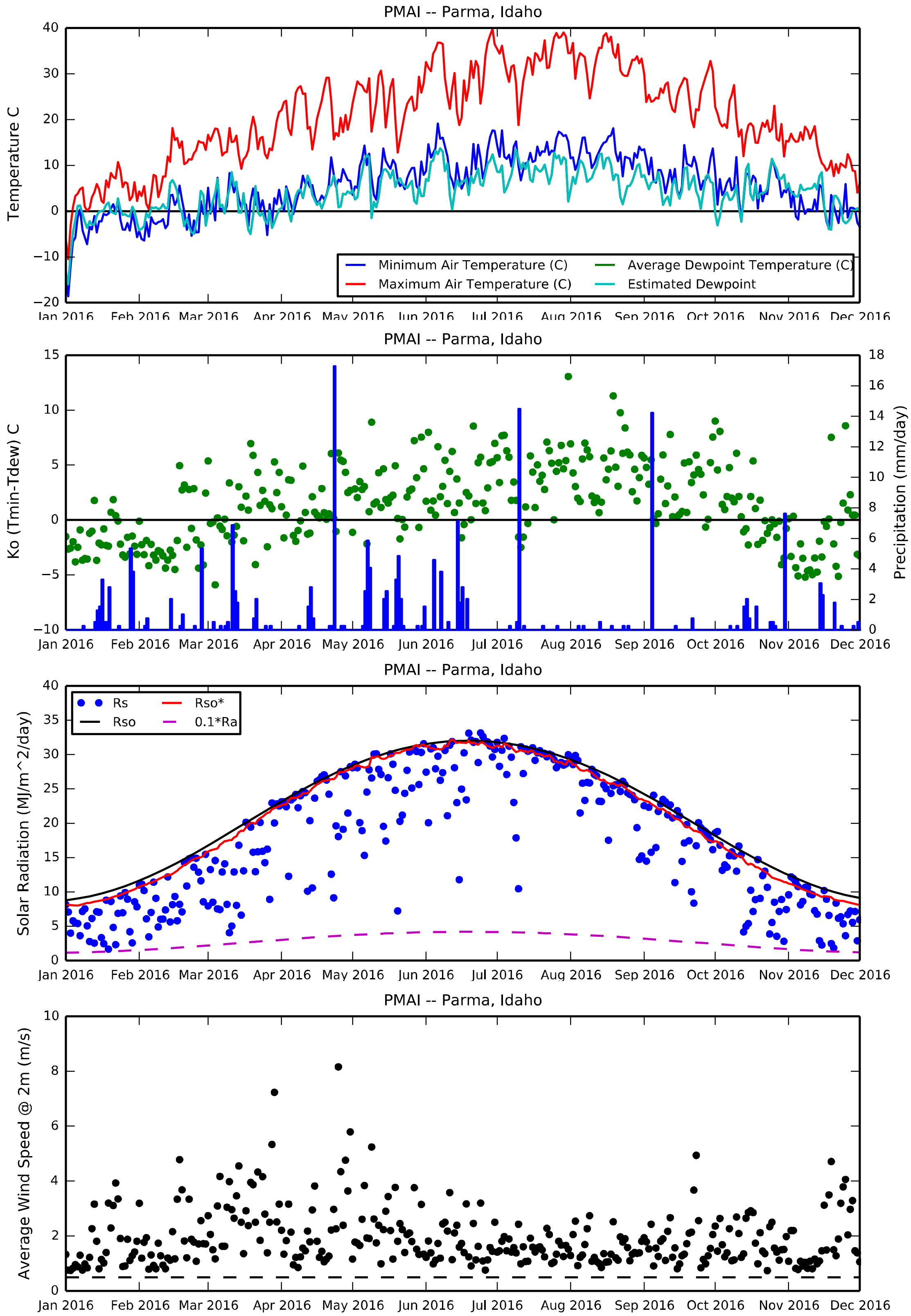


Figure 72. Parma ID (PMAI) meteorological time series (Est.Tdew = Ave.Tdew).

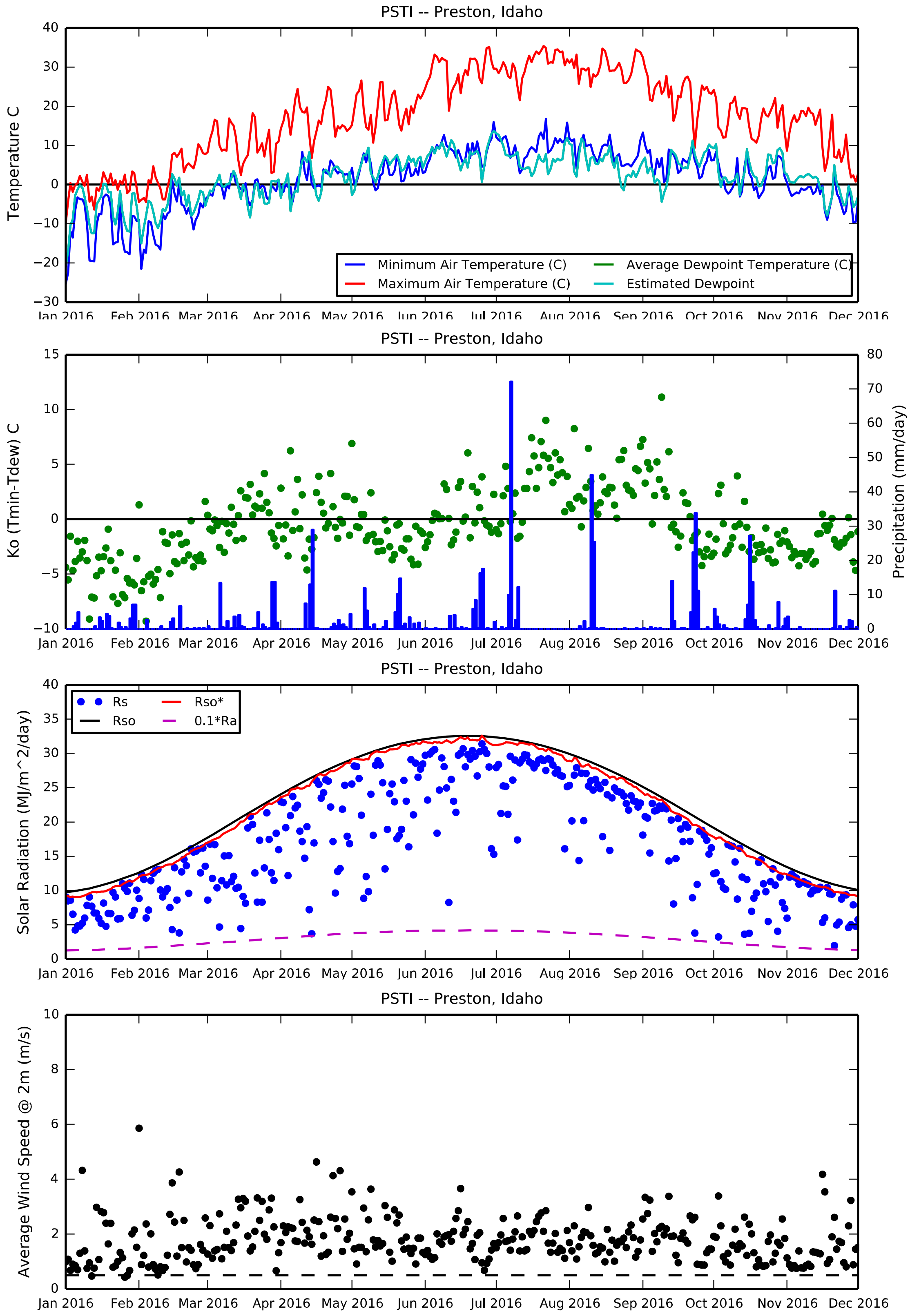


Figure 73. Preston, ID (PSTI) meteorological time series (Est.Tdew = Ave.Tdew).

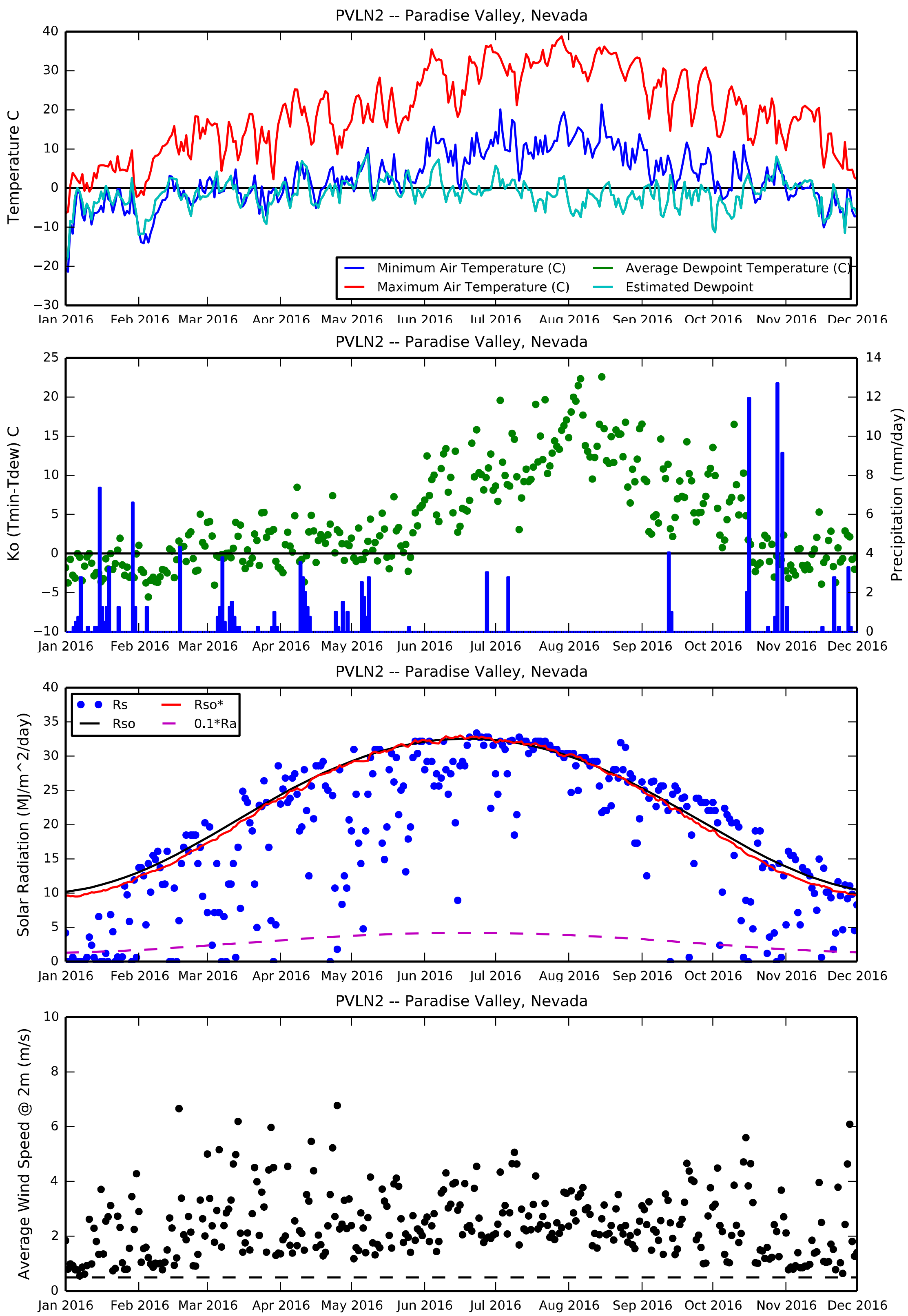


Figure 74. Paradise Valley NV (PVLN2) meteorological time series (Est.Tdew = Ave.Tdew).

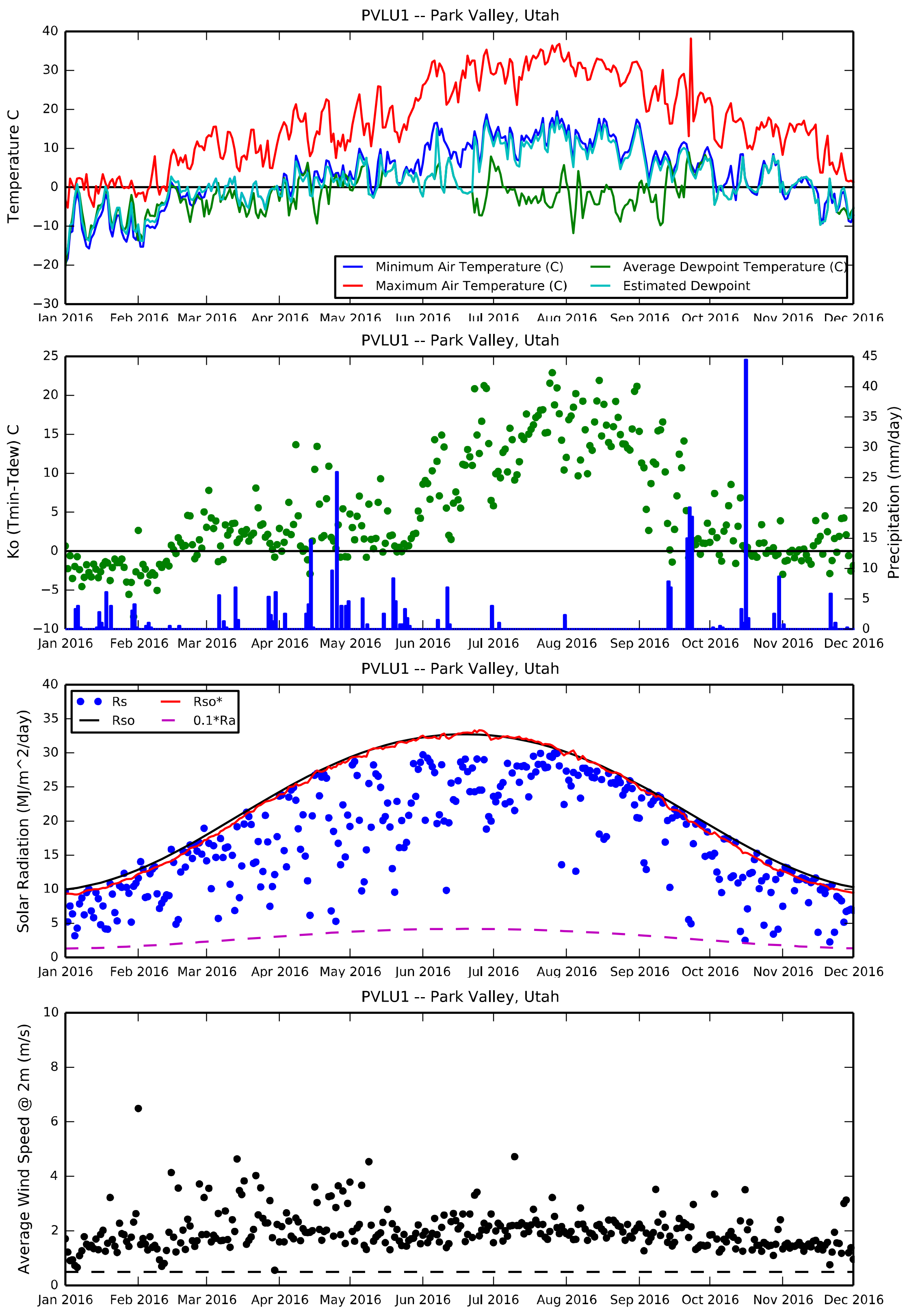


Figure 75. Park Valley UT (PVLU1) meteorological time series (Est.Tdew = f(ETIdaKo, Ave.Tdew).

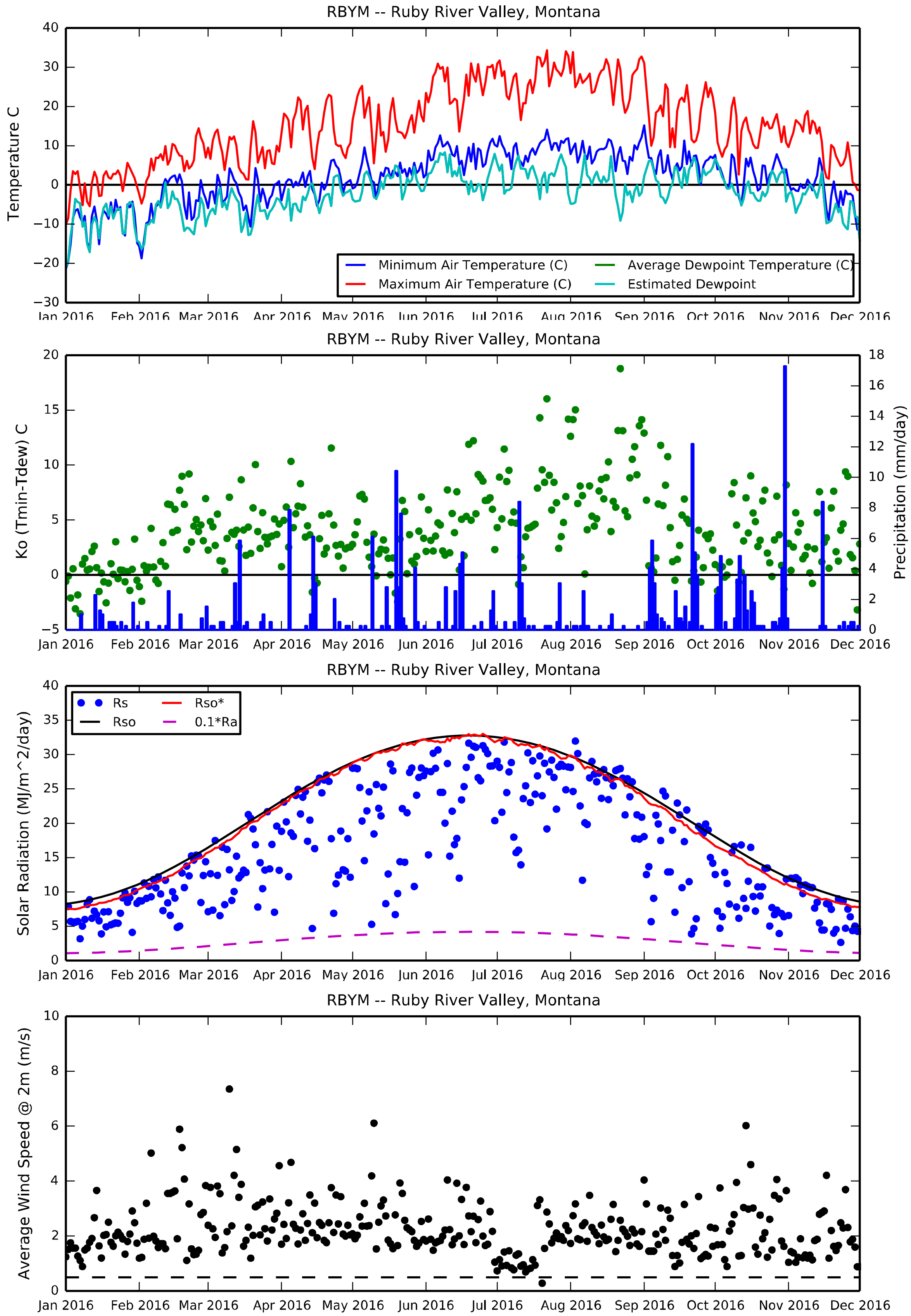


Figure 76. Ruby River Valley MT (RBYM) meteorological time series (Est.Tdew = Ave.Tdew).

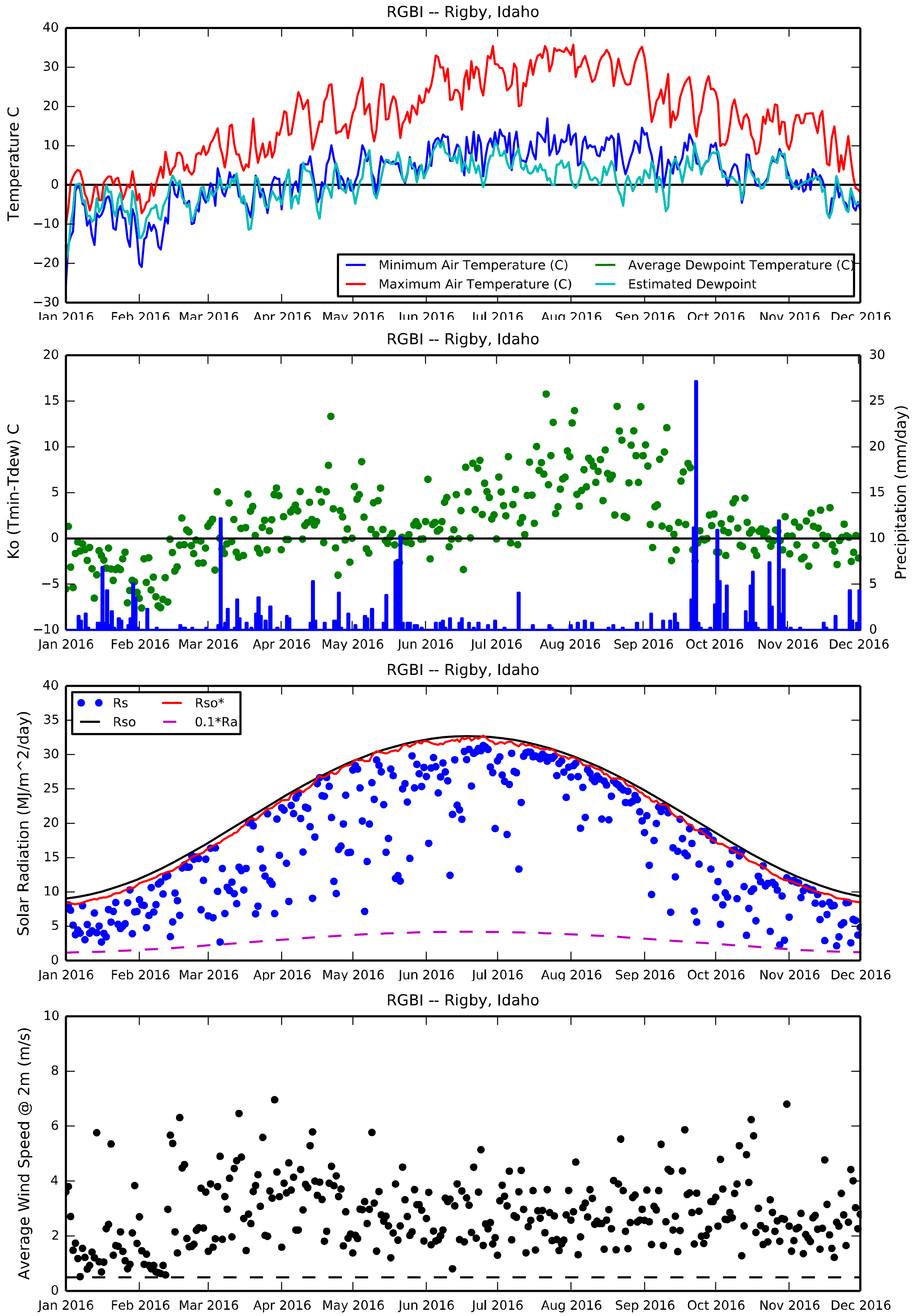


Figure 77. Rigby ID (RGBI) meteorological time series (Est.Tdew = Ave.Tdew).

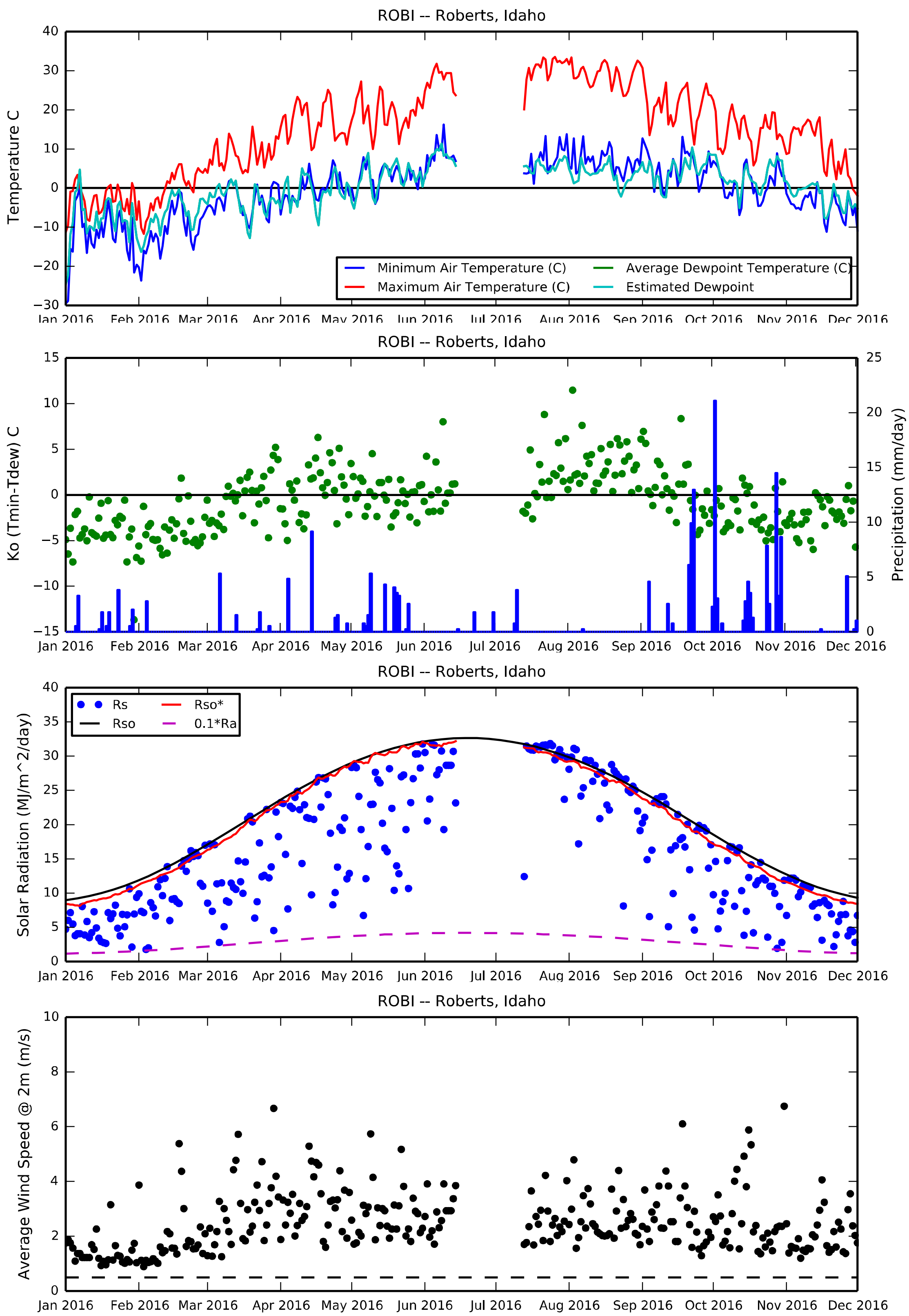


Figure 78. Roberts ID (ROBI) meteorological time series (Est.Tdew = Ave.Tdew).

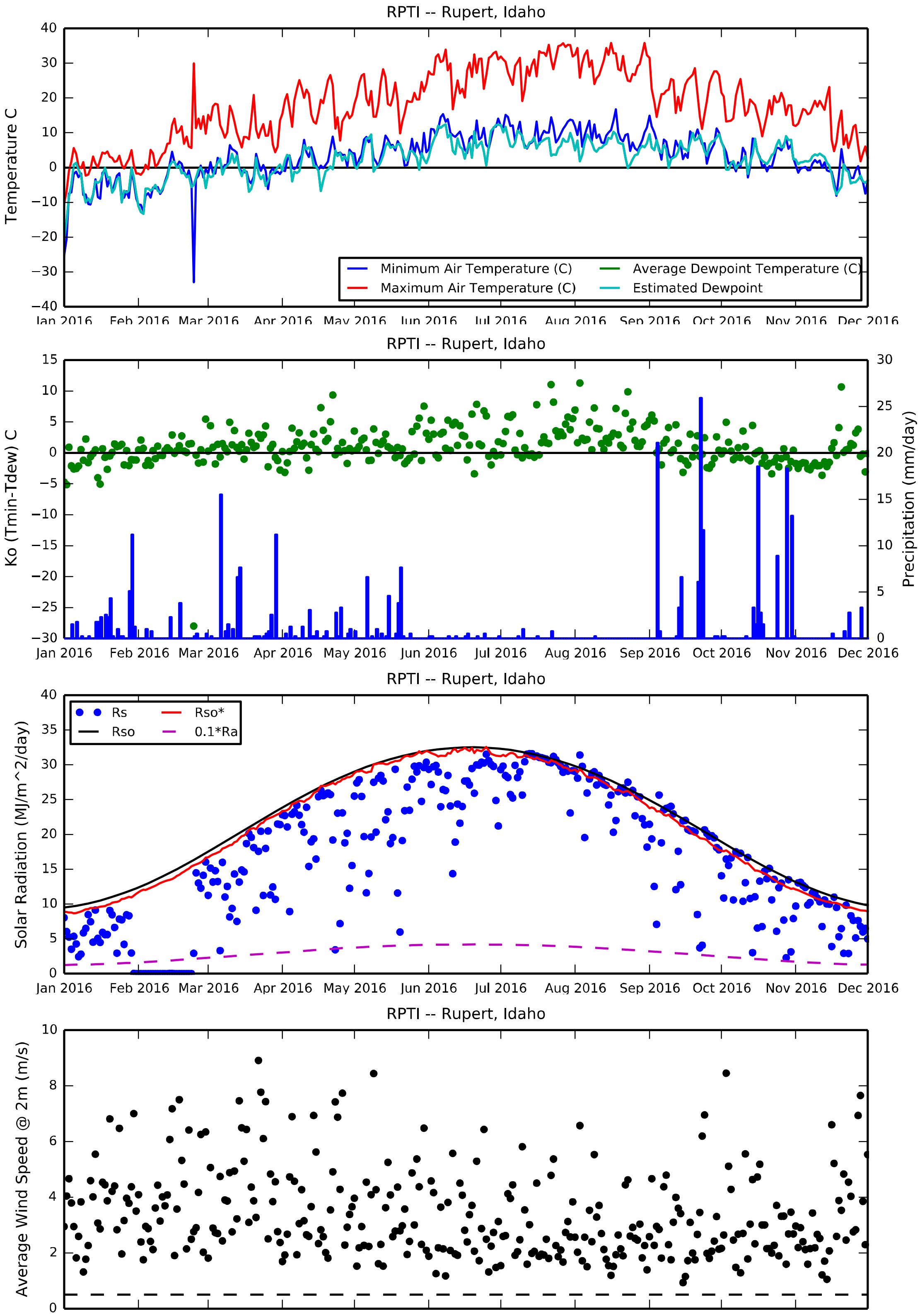


Figure 75: Rupert ID (RPTI) meteorological time series (Est.Tdew = Ave.Tdew).

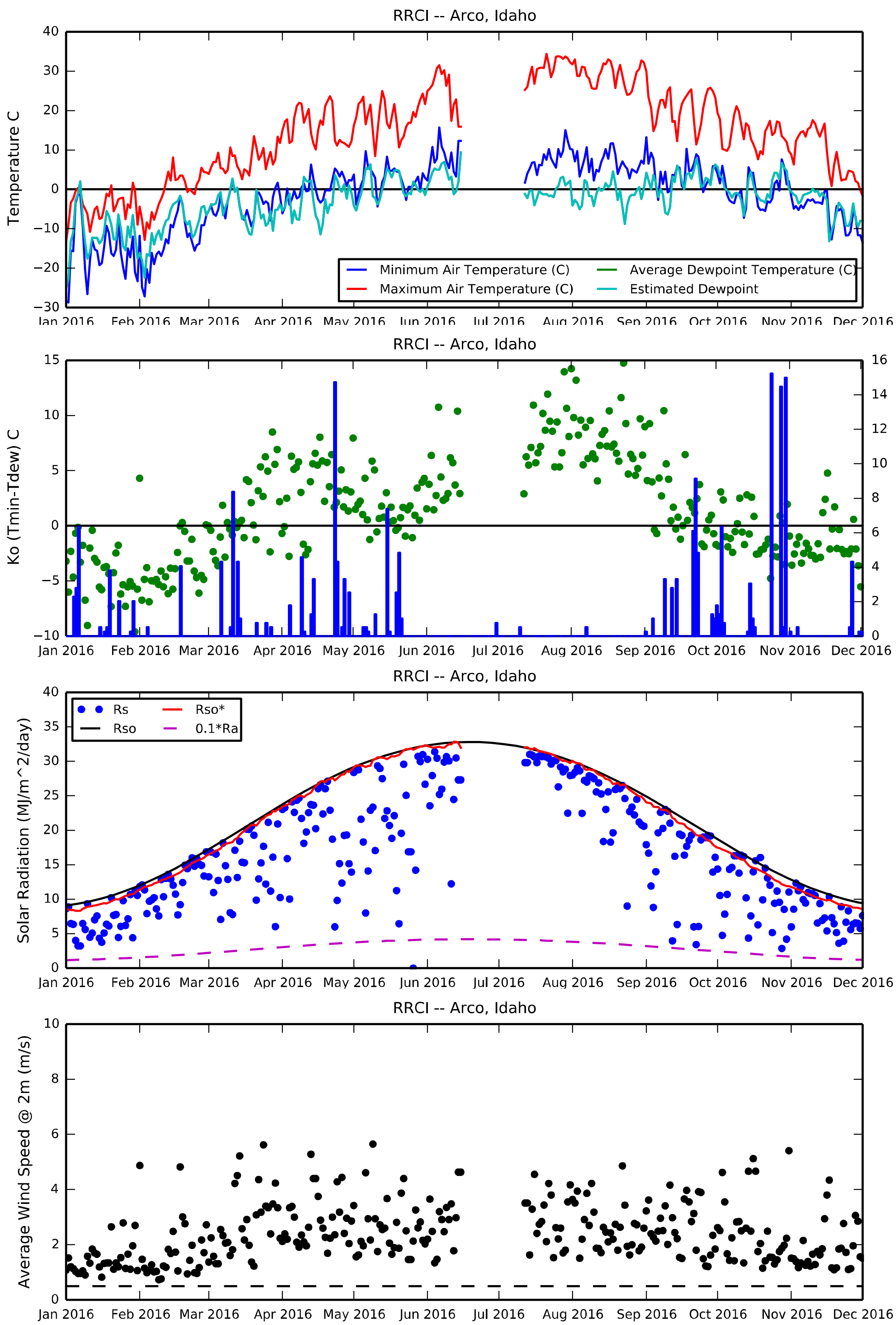


Figure 80. Arco ID (RRCI) meteorological time series (Est.Tdew = Ave.Tdew).

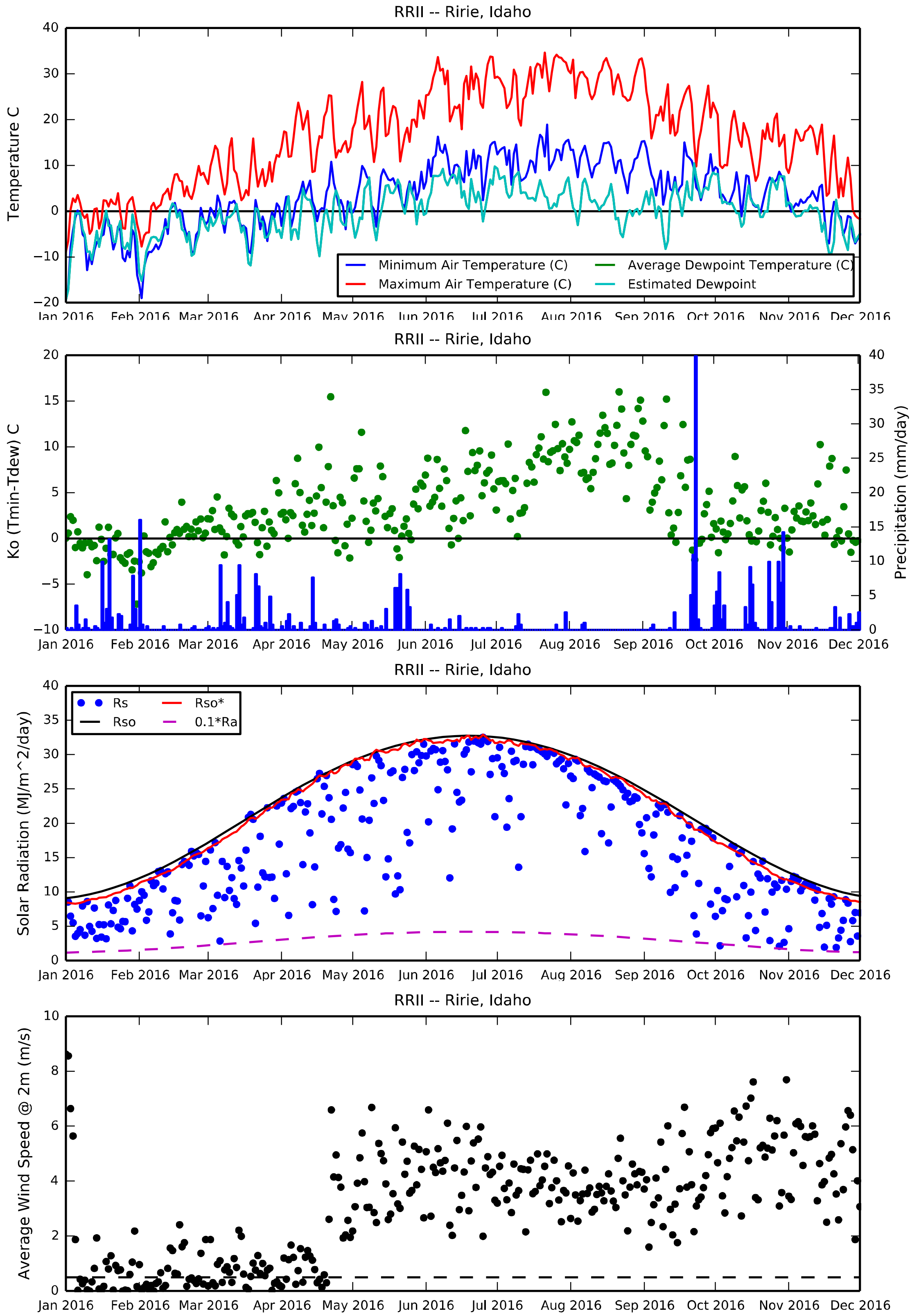


Figure 81. Ririe ID (RRII) meteorological time series (Est.Tdew = Ave.Tdew).

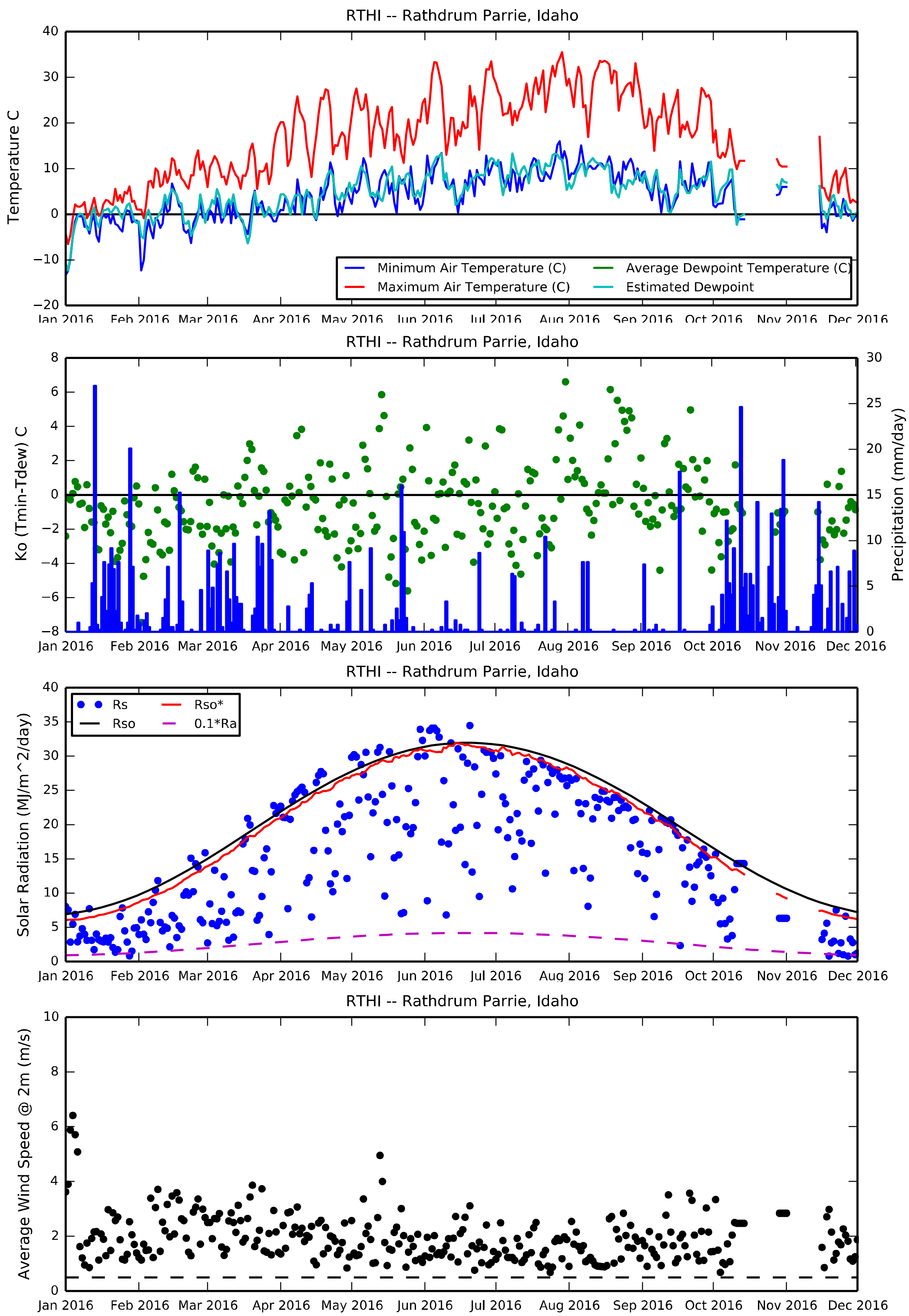


Figure 82. Rathdrum ID (RTHI) meteorological time series (Est.Tdew = Ave.Tdew).

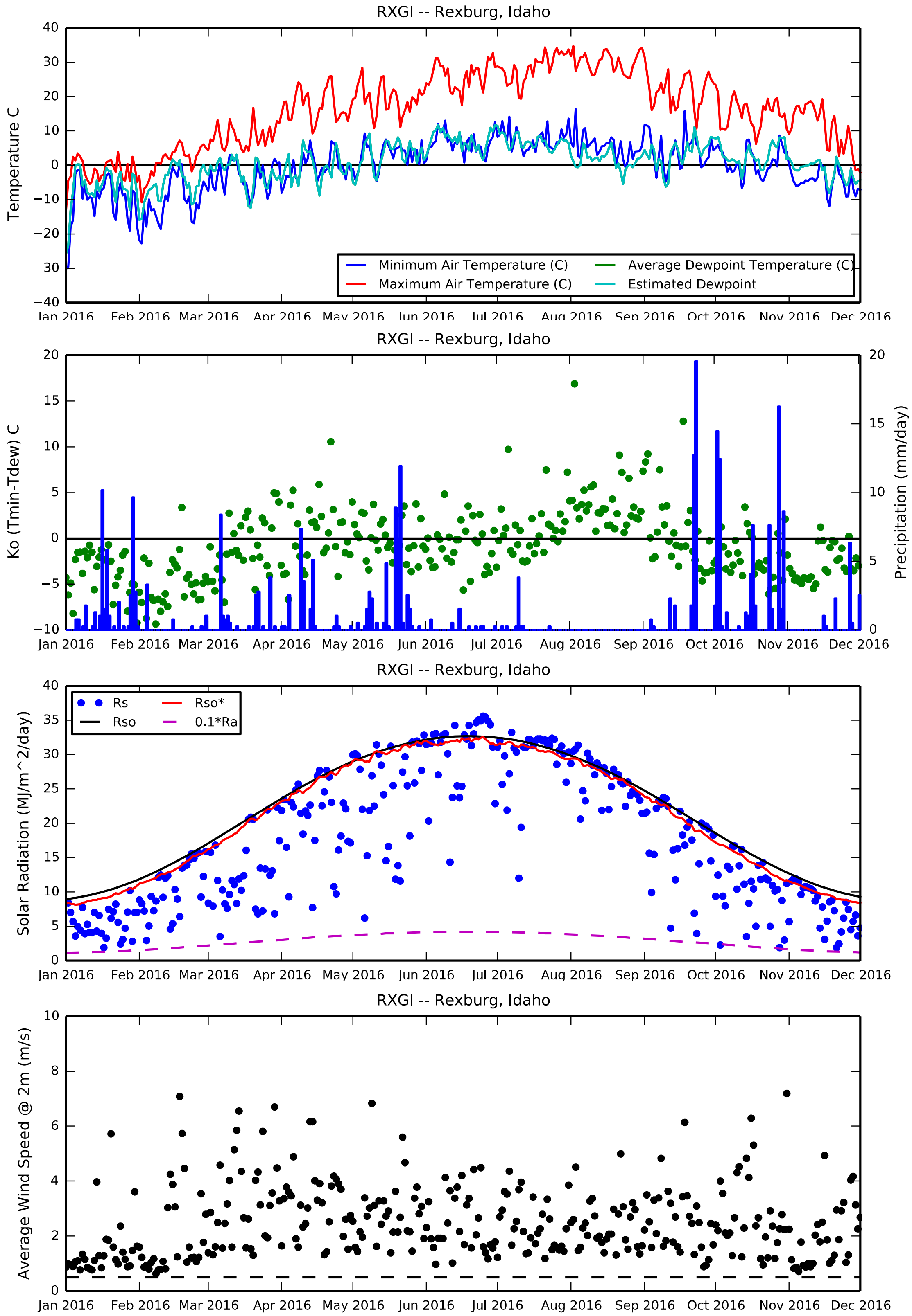


Figure 83. Rexburg ID (RXGI) meteorological time series (Est.Tdew = Ave.Tdew).

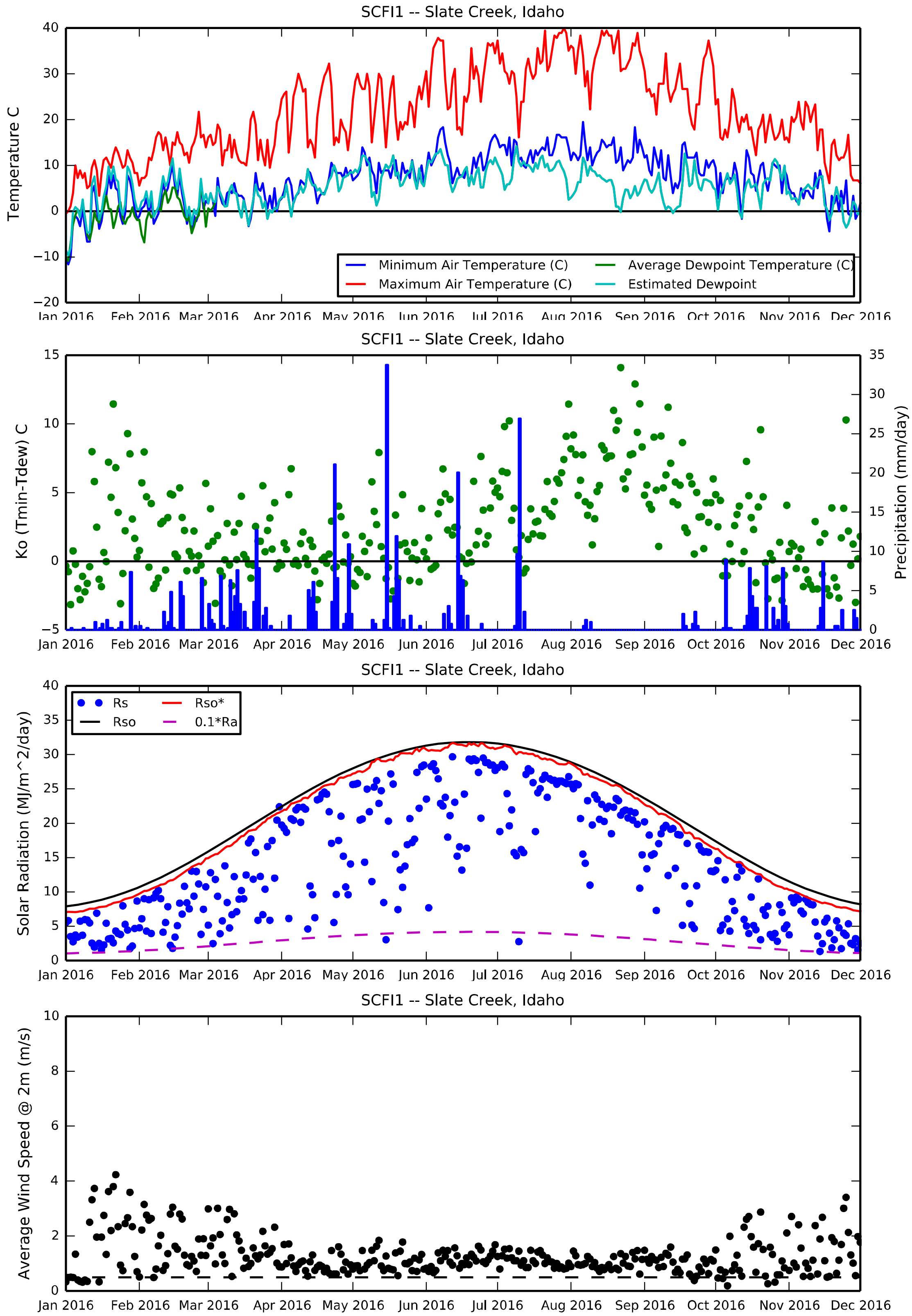


Figure 84. Slate Creek ID (SCFI1) meteorological time series (Est.Tdew = f(ETIdaKo, Ave.Tdew).

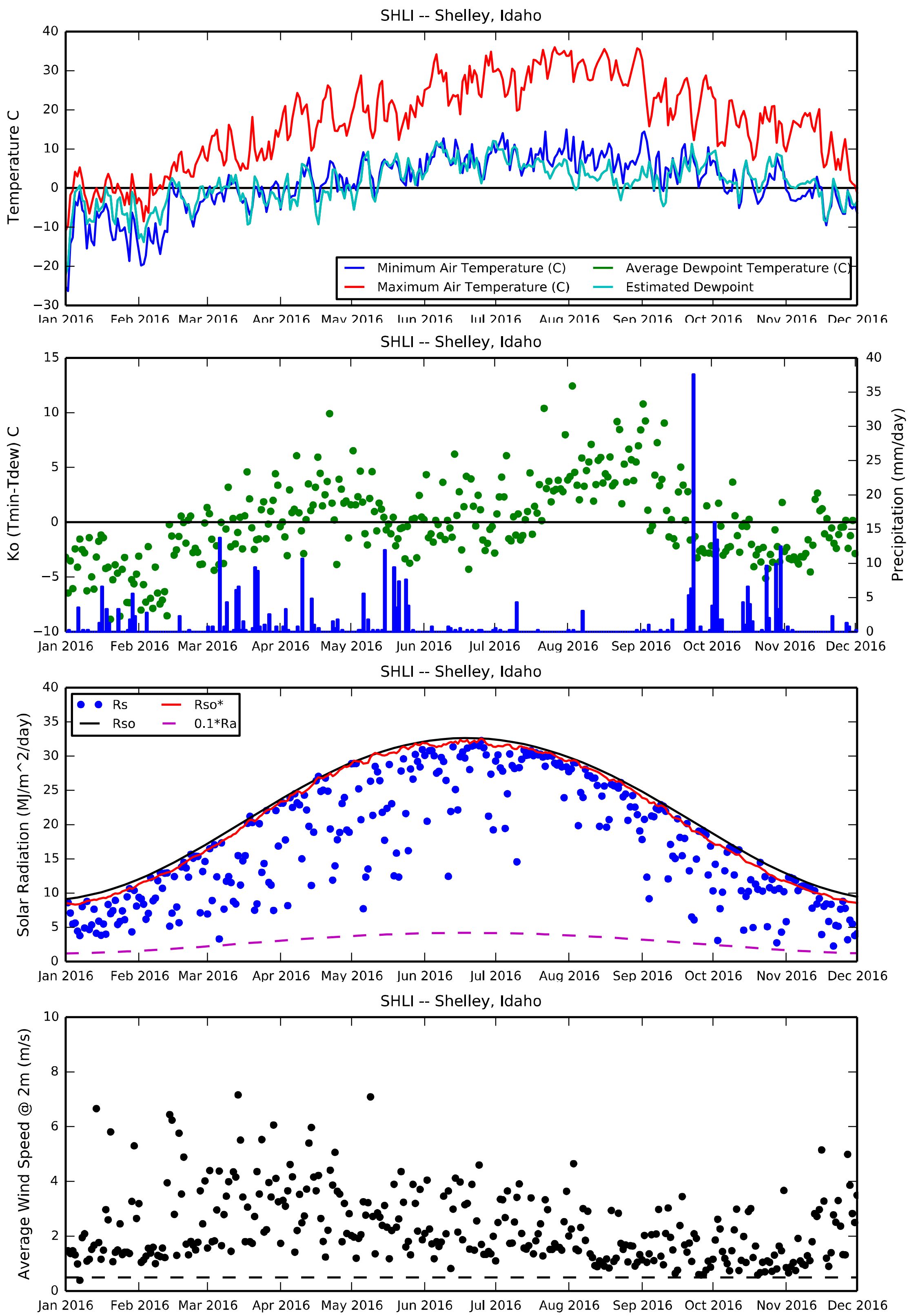


Figure 85. Shelly ID (SHLI) meteorological time series (Est.Tdew = Ave.Tdew).

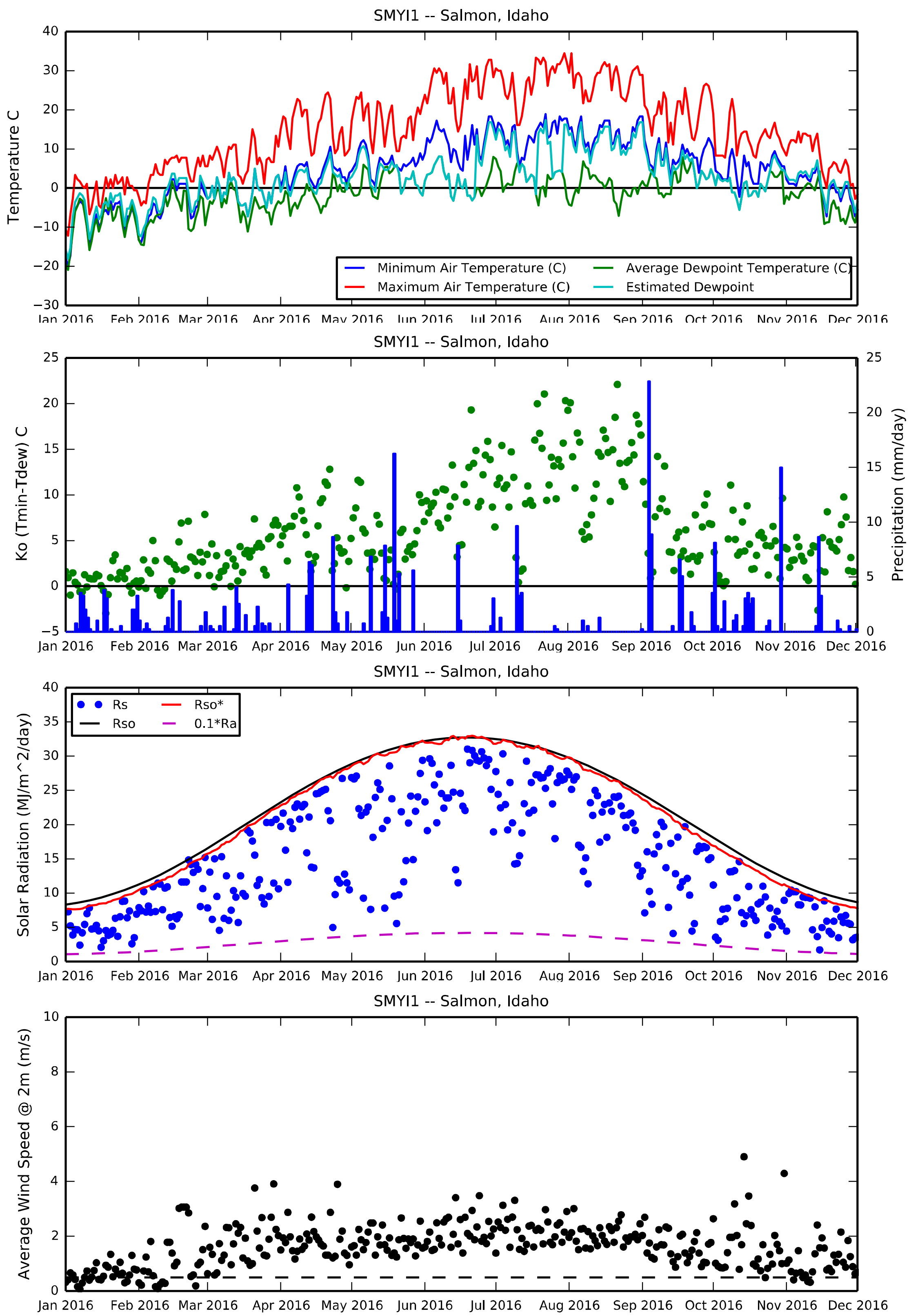


Figure 86. Salmon ID (SMYI1) meteorological time series (Est.Tdew = Ave.Tdew).

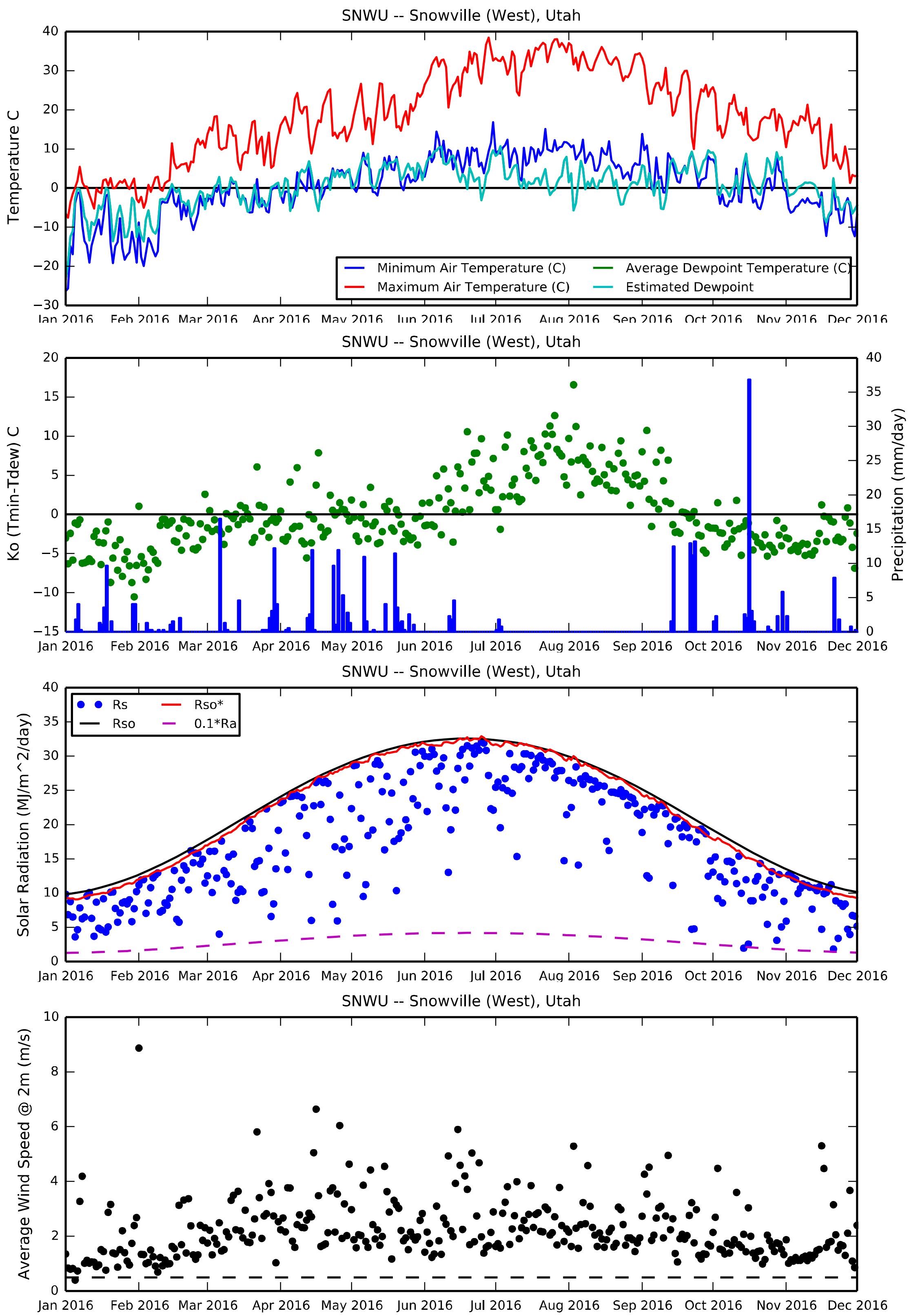


Figure 87. Snowville UT (SNWU) meteorological time series (Est.Tdew = Ave.Tdew).

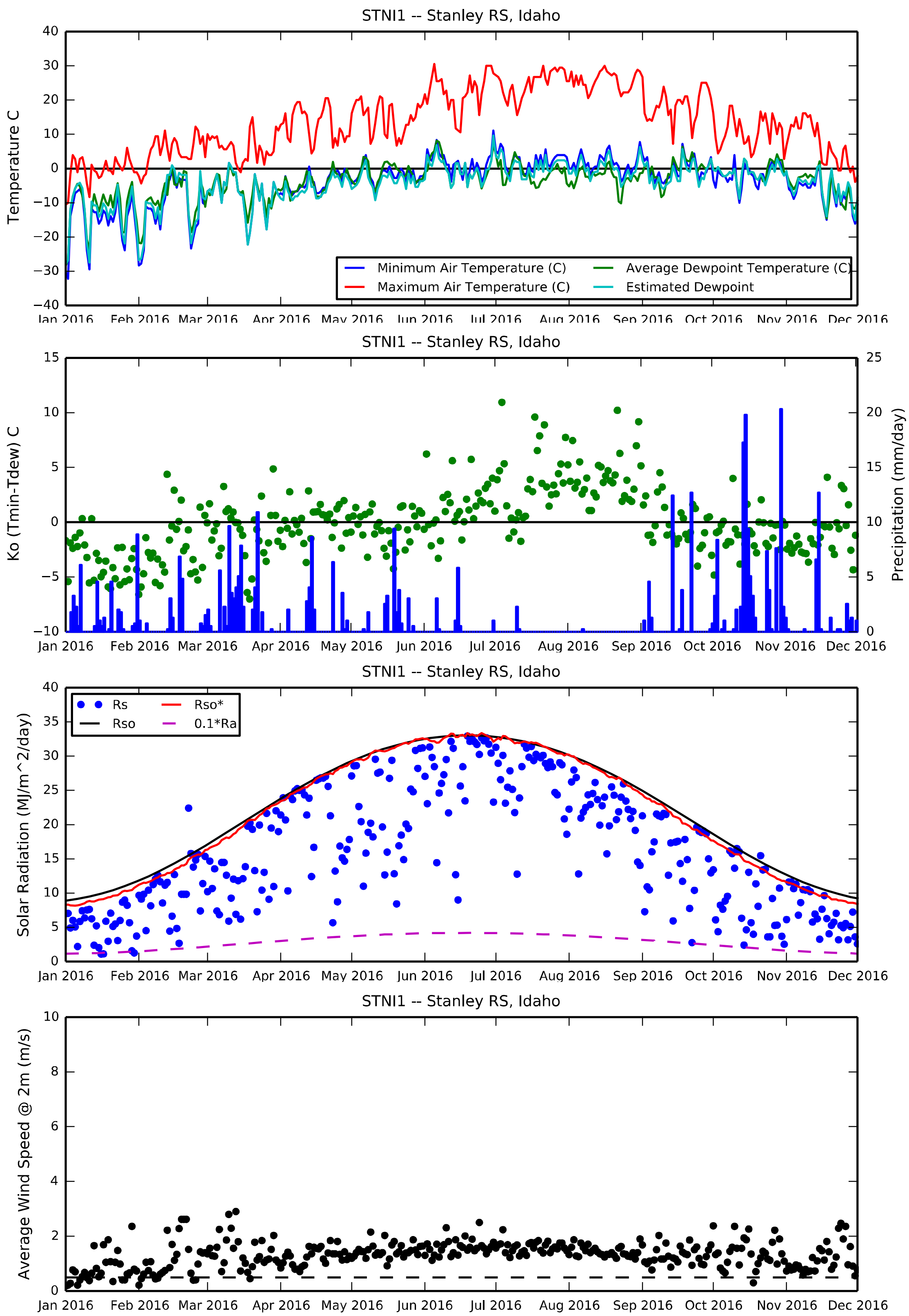


Figure 88. Stanley ID (STNI1) meteorological time series (Est.Tdew = f(ETIdaKo, Ave.Tdew).

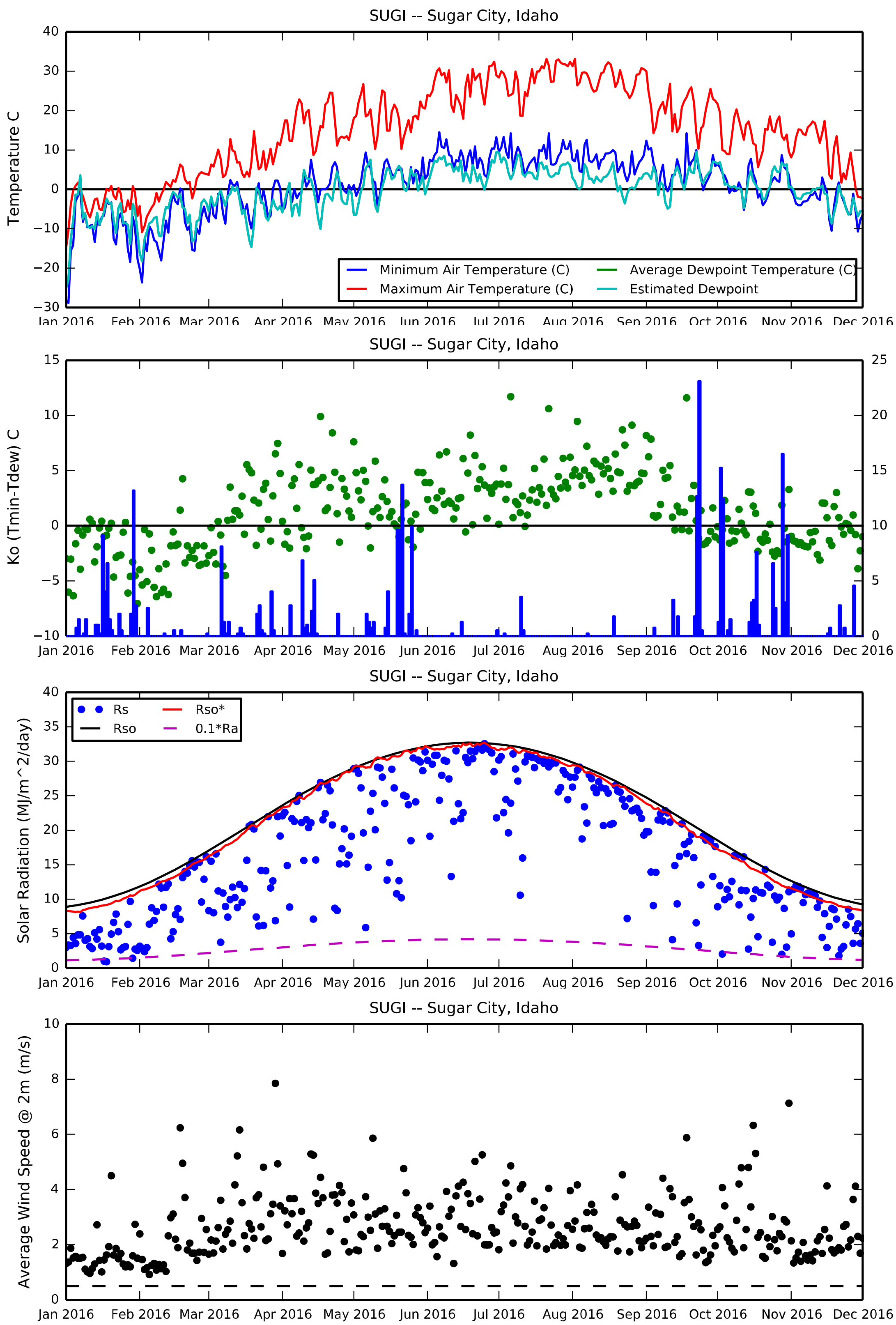


Figure 89. Sugar City ID (SUGI) meteorological time series (Est.Tdew = Ave.Tdew).

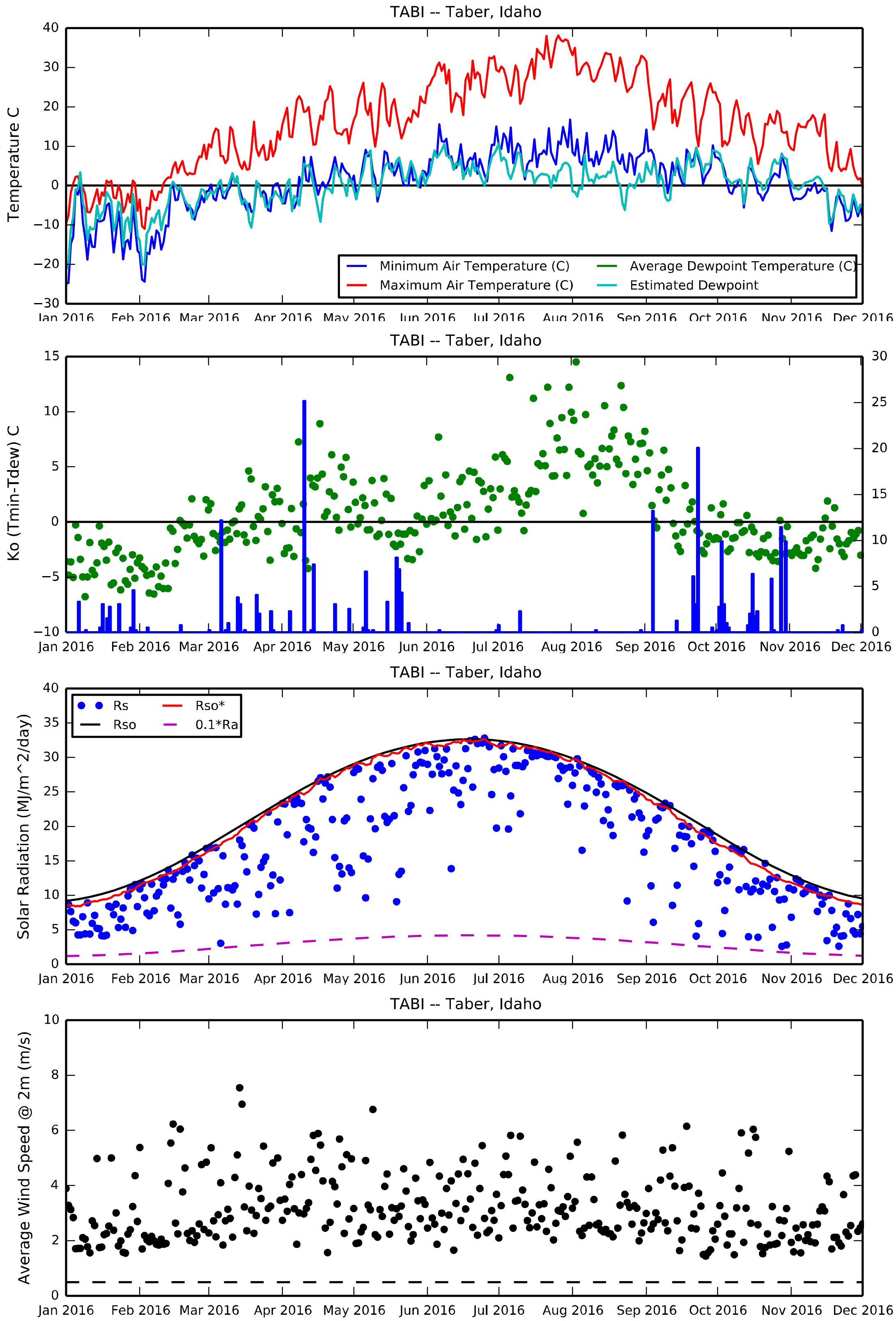


Figure 90. Taber ID (TABI) meteorological time series (Est.Tdew = Ave.Tdew).

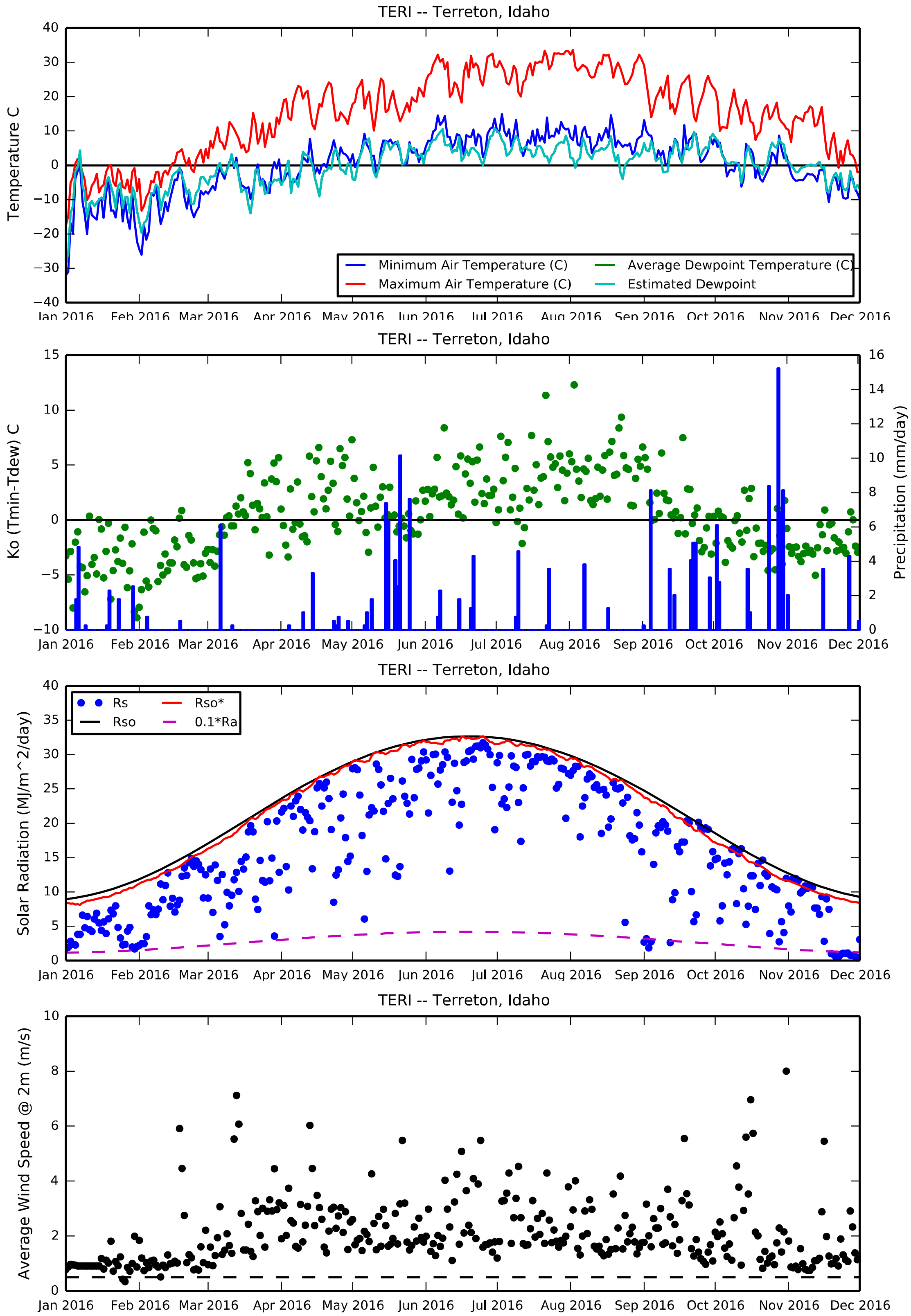


Figure 91. Terreton (INL) ID (TERI) meteorological time series (Est.Tdew = Ave.Tdew).

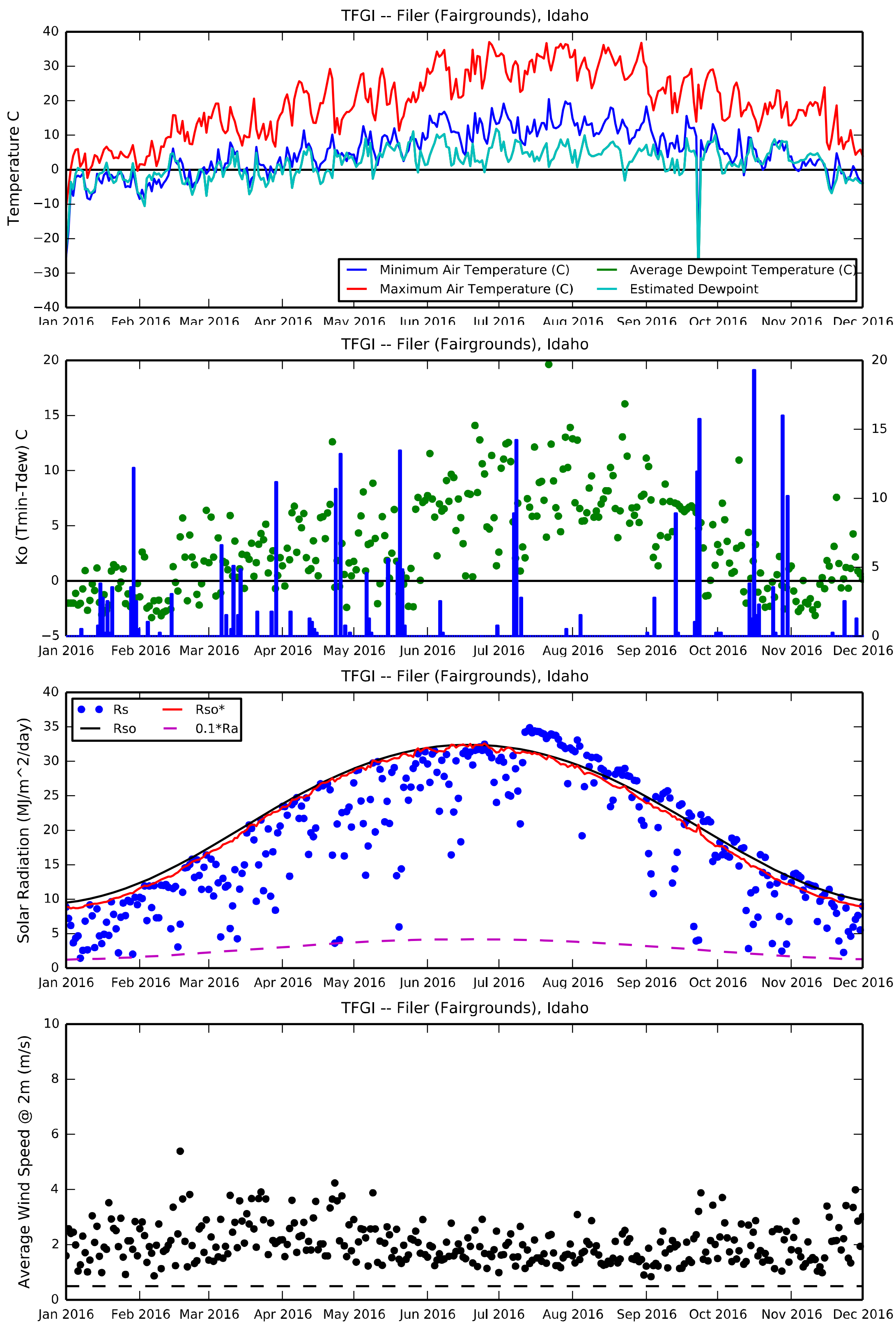


Figure 92. Twin Falls (Filer) ID (TFGI) meteorological time series (Est.Tdew = Ave.Tdew).

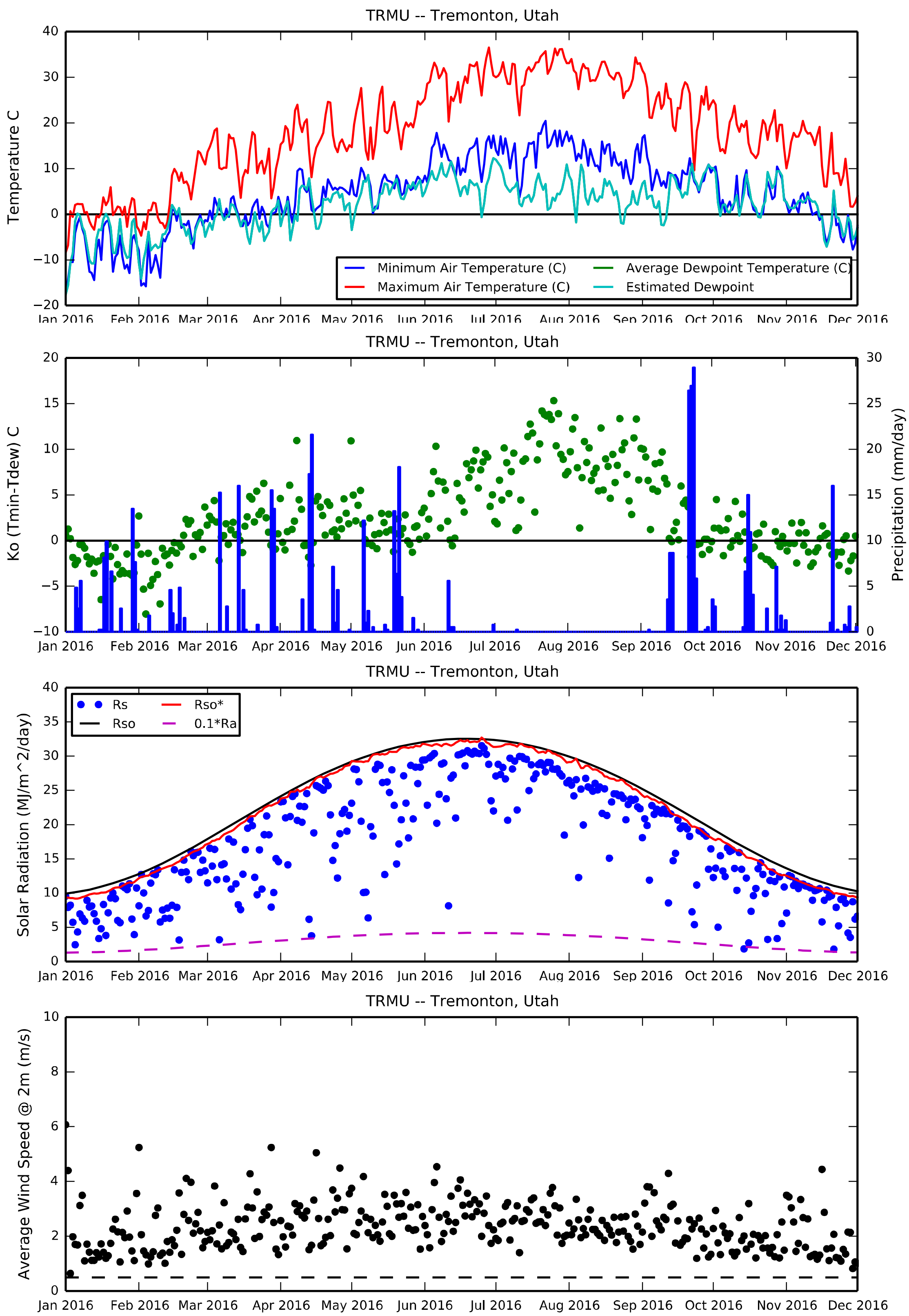


Figure 93. Tremonton UT (TRMU) meteorological time series (Est.Tdew = Ave.Tdew).

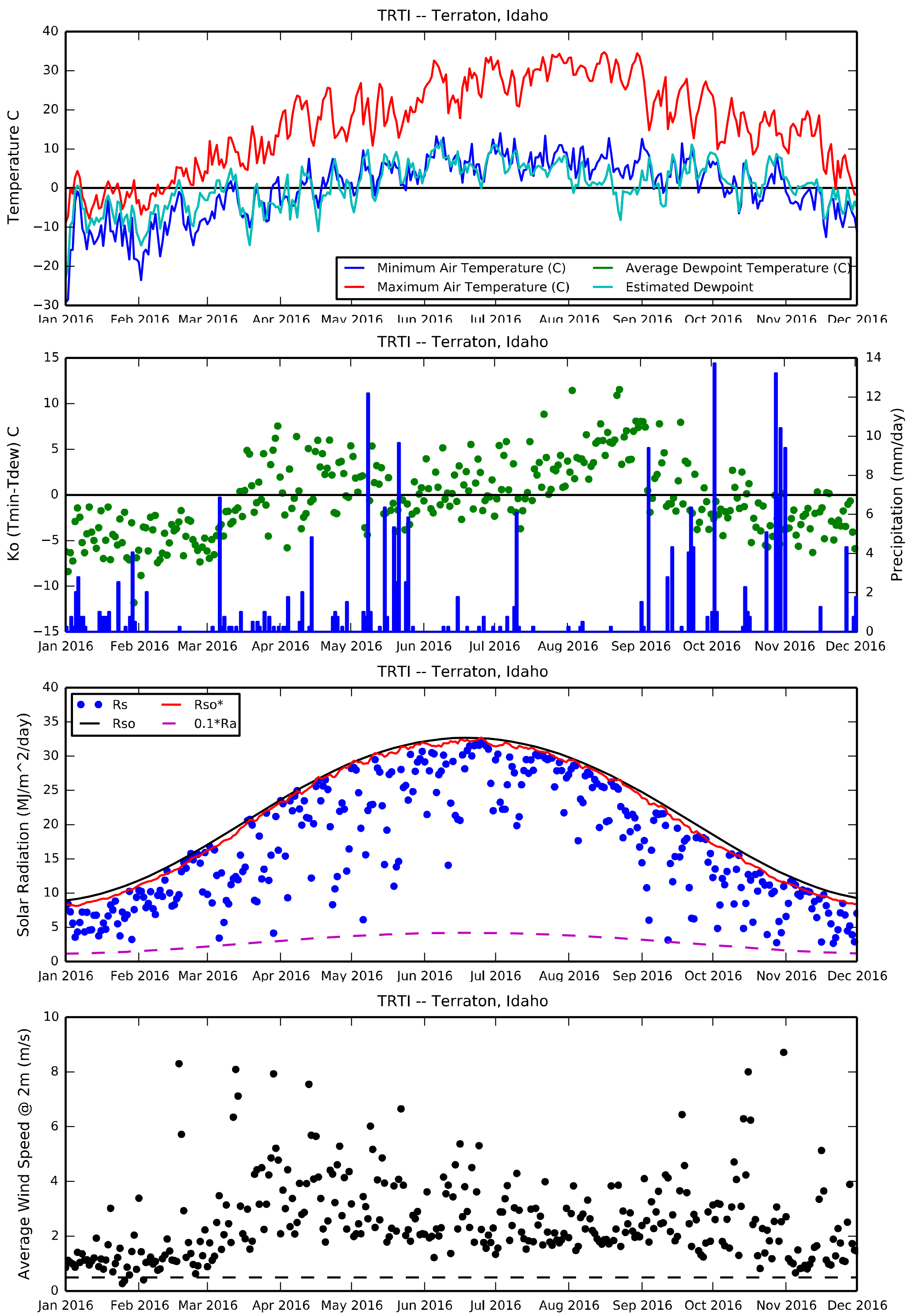


Figure 94. Terraton (PN-Agrimet) ID (TRTI) meteorological time series (Est.Tdew = Ave.Tdew).

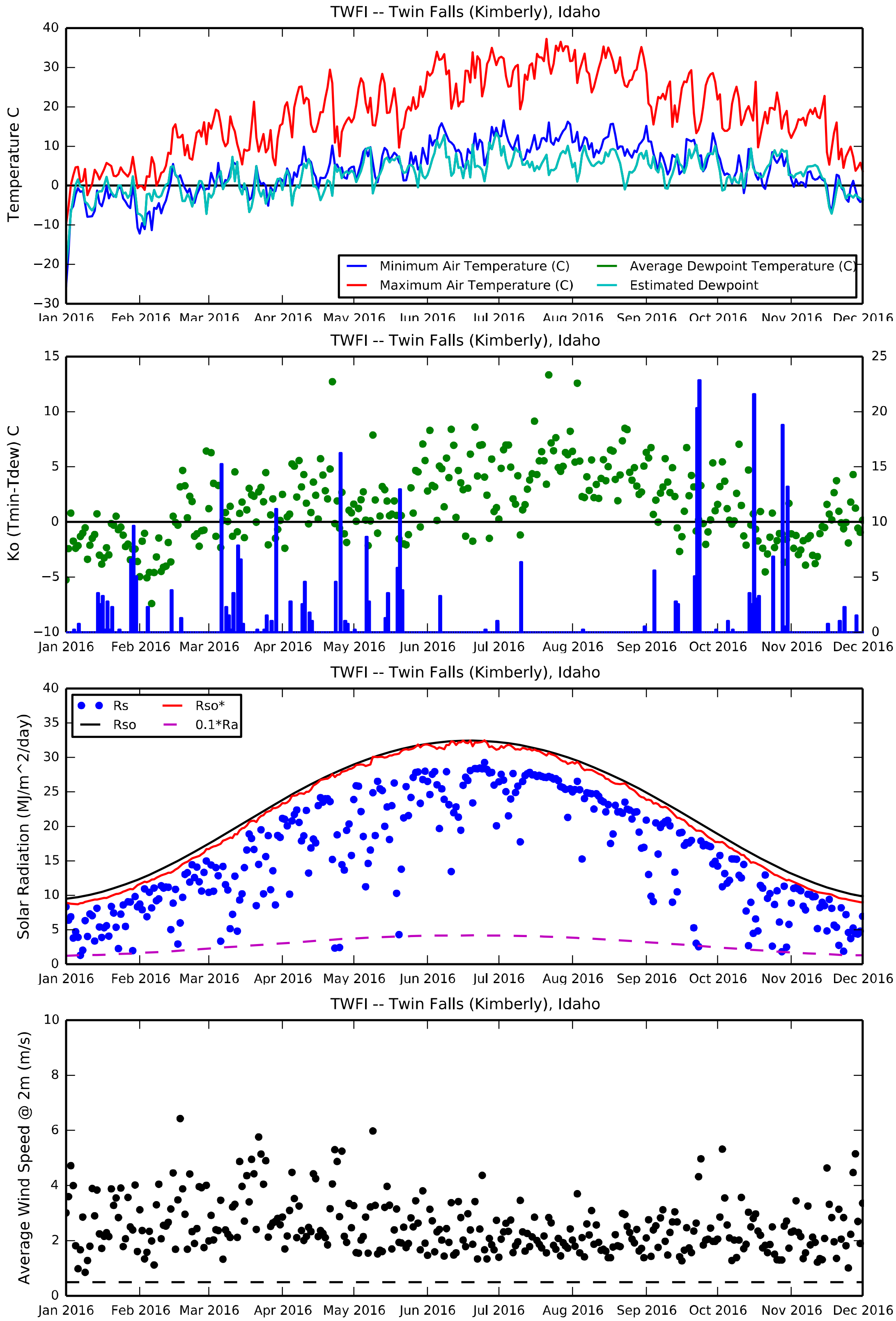


Figure 95. Twin Falls (Kimberly) ID (TWFI) meteorological time series (Est.Tdew = Ave.Tdew).

Appendix B: Synthetic Image Representing March 1, 2016

Synthetic Image for March 1, 2016 and Dormant Season K_c
Clarence Robison and Richard Allen

The interpolation of daily ET_rF (fraction of reference ET) images relies on an initial ET_FF image absent of missing ET_rF data for all pixels. For 2016, due to cloudy conditions for much of the March Landsat images, this initial image is a synthetic image derived from meteorological data, computed reference evapotranspiration, and land surface conditions. The synthetic image was developed to represent the ET_rF for the area on March 1, 2016. The scripts used to determine daily ET_r at meteorological sites are discussed in Appendix A.

The synthetic land surface conditions for the ESPA area are based on the Cropland Data Layer information for calendar year 2015 downloaded from CropScape[2] on March 3, 2016 and shown in Figure 96.

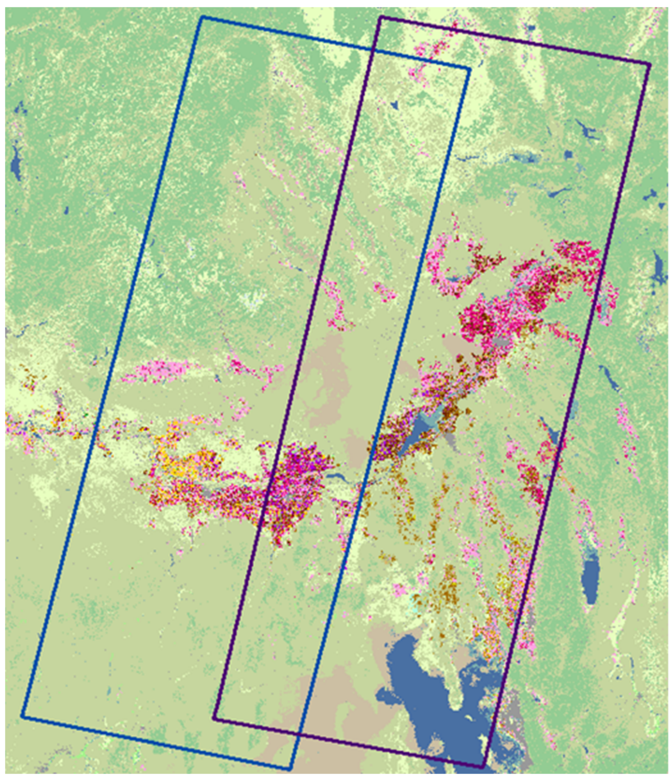


Figure 96. Cropland Data Layer for 2015 overlain by Landsat Path 40 and 39 outlines.

Year 2015 was concluded to be a reasonable proxy for year 2016 in terms of late winter – early spring ground-cover conditions. The surface vegetation identified from the 2015 CDL layer was translated into vegetation classes found in ETIdaho[3] as summarized in Table 11. This

[2] USDA National Agricultural Statistics Service Cropland Data Layer. 2015. Published crop-specific data layer [Online]. Available at https://nassgeodata.gmu.edu/CropScape/ (accessed March 3, 2016). USDA-NASS, Washington, DC.

[3] Evapotranspiration and Consumptive Irrigation Water Requirements for Idaho, Allen, R.G. and Robison, C. W. http://data.kimberly.uidaho.edu/ETIdaho

translation was patterned after translations made for generation of synthetic images for METRIC ESPA applications for years 1986 and 2009. The class translations reduced the number of vegetation classes to 32 as shown in Figure 97.

Table 11. Cropland Data Layer Type Translation to ETIdaho Cover Type

CropScape Cover	ETIdaho Cover	CropScape Cover	ETIdaho Cover
Corn	Silage Corn	Forest	Poplar Trees
Sorghum	Silage Corn	Cherries	Orchard w/gc
Soybeans	Dry Beans	Peaches	Orchard w/gc
Sweet Corn	Sweet Corn	Apples	Orchard w/gc
Pop Corn	Field Corn	Grapes	Wine Grapes
Barley	Spring Grain	Christmas Trees	Willows
Durum Wheat	Winter Grain	Pears	Orchard w/gc
Spring Wheat	Spring Grain	Open Water	Open Water/Ponds
Winter Wheat	Winter Grain	Perennial Ice/Snow	Perennial Ice/Snow
Other Small Grains	Spring Grain	Developed/Open Space	Turf
Rye	Spring Grain	Developed/Low Intensity	Turf
Oats	Spring Grain	Developed/Med Intensity	Mulch
Millet	Spring Grain	Developed/High Intensity	Bare
Speltz	Winter Grain	Barren	Bare
Canola	Canola	Deciduous Forest	Poplar Trees
Flaxseed	Canola	Evergreen Forest	Cottonwoods
Safflower	Safflower	Mixed Forest	Willows
Mustard	Mustard	Shrubland	Sagebrush
Alfalfa	Alfalfa/Less	Grassland/Herbaceous	Range Grasses
Other Hay/Non Alfalfa	Grass Hay	Grass/Pasture	Grass Pasture
Camelina	Mustard	Pasture/Hay	Grass Hay
Sugarbeets	Sugar Beets	Woody Wetlands	Wetlands
Dry Beans	Dry Beans	Herbaceous Wetlands	Wetlands
Potatoes	Potatoes	Triticale	Winter Grain
Other Crops	Garden Vegs	Carrots	Carrots
Misc Vegs & Fruits	Garden Vegs	Cantaloupes	Melons
Onions	Onions	Peppers	Garden Vegs
Lentils	Lentils	Plums	Orchard w/gc
Peas	Peas -- Seed	Squash	Melons
Tomatoes	Garden Vegs	Dbl Crop WinWht/Corn	Winter Grain
Herbs	Garden Vegs	Pumpkins	Melons
Clover/Wildflowers	Grass Pasture	Dbl Crop Barley/Corn	Winter Grain
Sod/Grass Seed	Turf	Radishes	Garden Vegs
Fallow/Idle Cropland	Mulch	Turnips	Garden Vegs

Because the synthetic image represents March 1, 2016; the spatially interpolated 30-day mean air temperature from Feb 1 thru Mar 1 was examined and compared to green up thresholds used in ETIdaho (Figure 98a). In ETIdaho a 4°C 30 day mean temperature is required for initiation of spring grains and 5°C for green up of pasture and grass/turfs. In ETIdaho alfalfa green up date is not estimated with a T30 threshold; however, a cumulative degree day (CDD) threshold of 240 C-days from January 1 signals green-up. For winter grains, the crop coefficient (K_c or ET_rF) transitions from a “dormant” type value (0.12) to a green up value (0.15) at approximately 270 C-days from October 1st of the preceding year. For this analysis, green up of winter wheat is assumed

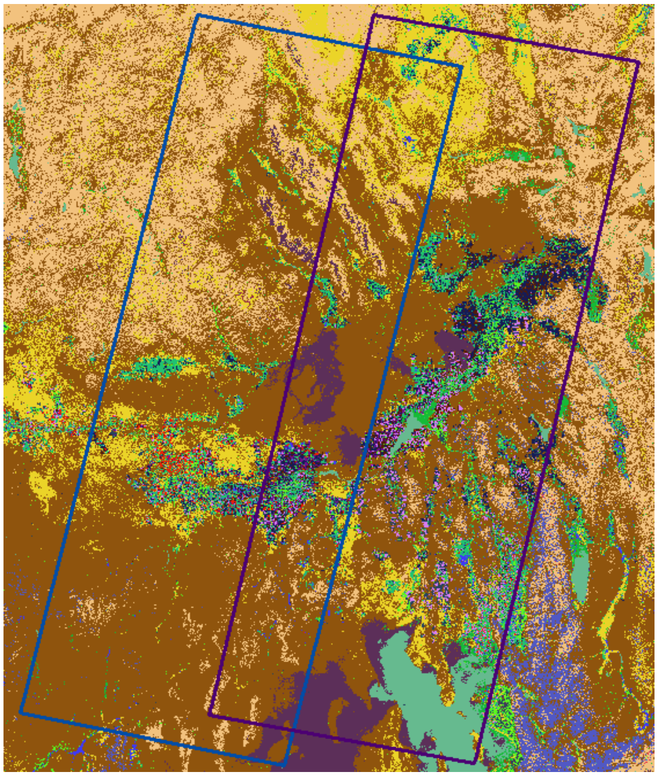


Figure 97. ETIdaho Surface Cover Classification for 2015.

to occur at 170 C-Days from January 1st. Currently, the meteorological and reference ET (ET_r) calculation scripts for near – real time METRIC start the collection of AWS data on January 1. Figure 98b shows the interpolated January based CGGD surface for the area on March 1st.

Based on the 30-day mean temperature and cumulative degree days shown in Figure 98 and the thresholds and growing-degree-day algorithms from ETIdaho; the vegetation conditions for March 1, 2016 are estimated to be dormant. There are three types of dormant surface conditions in ETIdaho: bare soil, mulch, and dormant turf. Thus the 2015 ETIdaho surface cover classifications shown in Figure 97 were re-classed to an ETIdaho dormant condition for each vegetation cover (Table 12) as shown in Figure 99 and are assumed to be the dormant conditions for March 1, 2016.

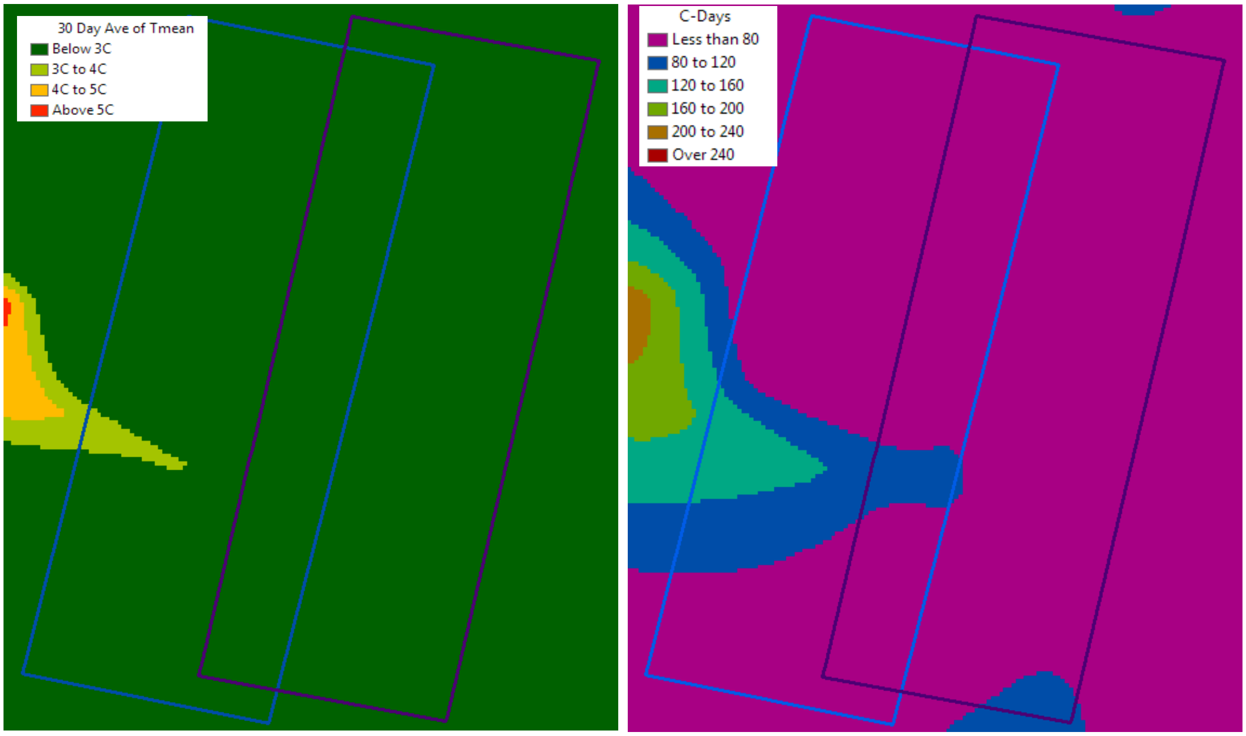


Figure 98. (a) 30-Day average mean Air Temperature (left) – (b) Cumulative degree days since January 1, 2016 (right) on March 1, 2016 based on the provisional meteorological data.

Table 12. ETIdaho surface cover type and associated dormant condition.

Cover	**Dormant**	**Cover**	**Dormant**	**Cover**	**Dormant**
Alfalfa/Less	Bare Soil	Garden Vegs	Bare Soil	Canola	Mulch
Grass Hay	Turf	Carrots	Bare Soil	Mustard	Mulch
Grass Pasture	Turf	Onions	Bare Soil	Bare	Bare Soil
Dry Beans	Bare Soil	Melons	Bare Soil	Mulch	Mulch
Silage Corn	Bare Soil	Wine Grapes	Bare Soil	Range Grasses	Mulch
Sweet Corn	Bare Soil	Peas -- Seed	Bare Soil	Sagebrush	Mulch
Field Corn	Bare Soil	Potatoes	Bare Soil	Wetlands	Mulch
Spring Grain	Mulch	Sugar Beets	Bare Soil	Cottonwoods	Mulch
Winter Grain	Mulch	Poplar Trees	Mulch	Willows	Mulch
Turf	Turf	Lentils	Bare Soil	Water	Water
Orchard w/gc	Mulch	Safflower	Mulch		

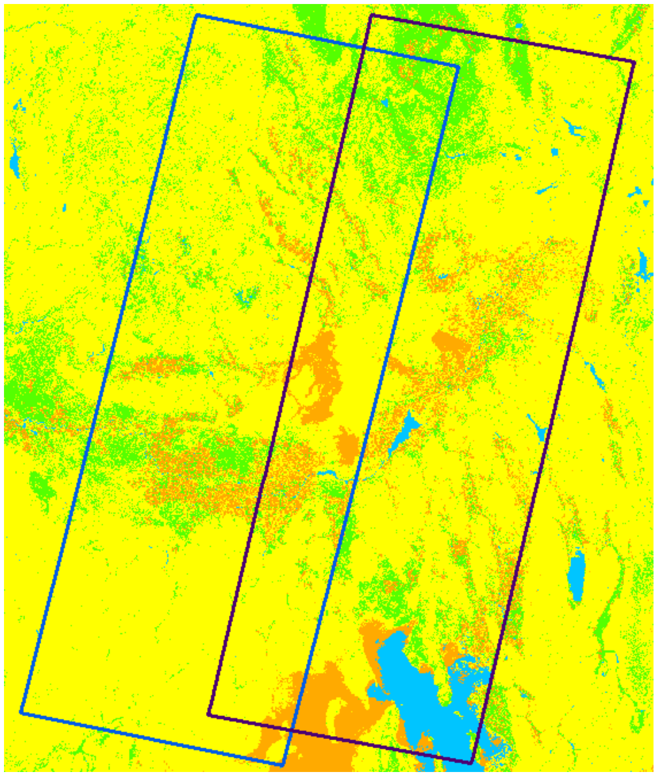


Figure 99. March 1, 2016 Dormant cover classification based on ETIdaho and 2015 CDL.

To determine the ET_rF (K_c) on March 1st, the K_c (ET_rF) for the four conditions were calculated using the procedures outlined in ETIdaho and meteorological data from automatic weathers stations in and surrounding the study area. The dormant condition ET_rF surface was interpolated from the AWS stations listed in Table 9 and shown in Figure 29 and described in Appendix A, The spatial interpolation was done using a weighted spline (1/3) and natural neighbor interpolation (2/3) processes included in ArcGIS. The synthetic ET_rF image representing March 1, 2016 for the ESPA (Paths 39 and 40) was constructed by sampling the appropriate interpolated raster based on dormant cover classification shown in Figure 99, and is shown in Figure 100.

ET_rF (or K_c) for the ET_{Idaho} dormant conditions was calculated as a mixture of K_e from the soil surface water balance for assumed bare areas of the ground surface and residual evaporation (0.1) from the organic cover. The "effective cover" was adjusted to meet the upper thresholds documented in the ETIdaho report when K_e = 1. (page 170).

Water	0.6
Bare Soil K_c:	$0.1 < (1.0 – 0.0)*K_e + 0.1 <= 0.9$
Mulch K_c:	$0.1 < (1.0 – 0.25)*K_e + 0.1 <= 0.85$
Dormant Turf K_c:	$0.1 < (1.0 – 0.30)*K_e + 0.1 <= 0.80$

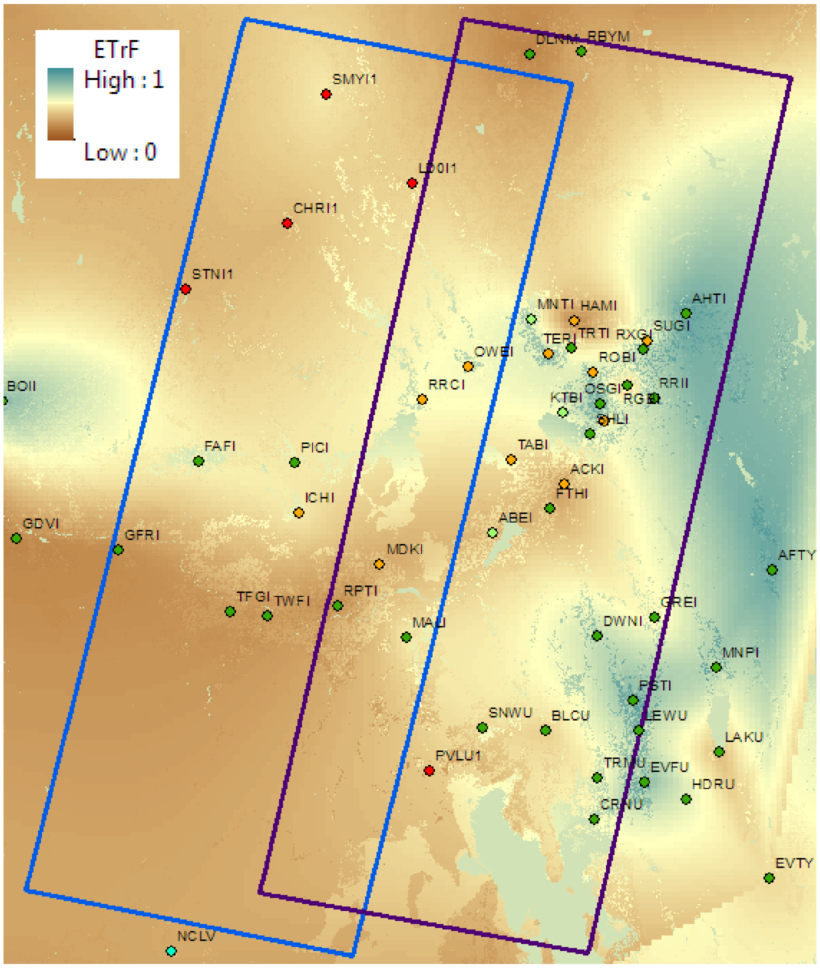


Figure 100. Synthetic ETrF image for March 1, 2016

Appendix C: METRIC Daily ET_rF Images

Ricardo Trezza and Carlos Kelly

Path 39

Daily ET_rF maps for path 39 are shown in Figure 101 to Figure 107. ***Masked cloud and shadow areas are shown as black***. The March 20th and September 28th images are clear, cloud free.

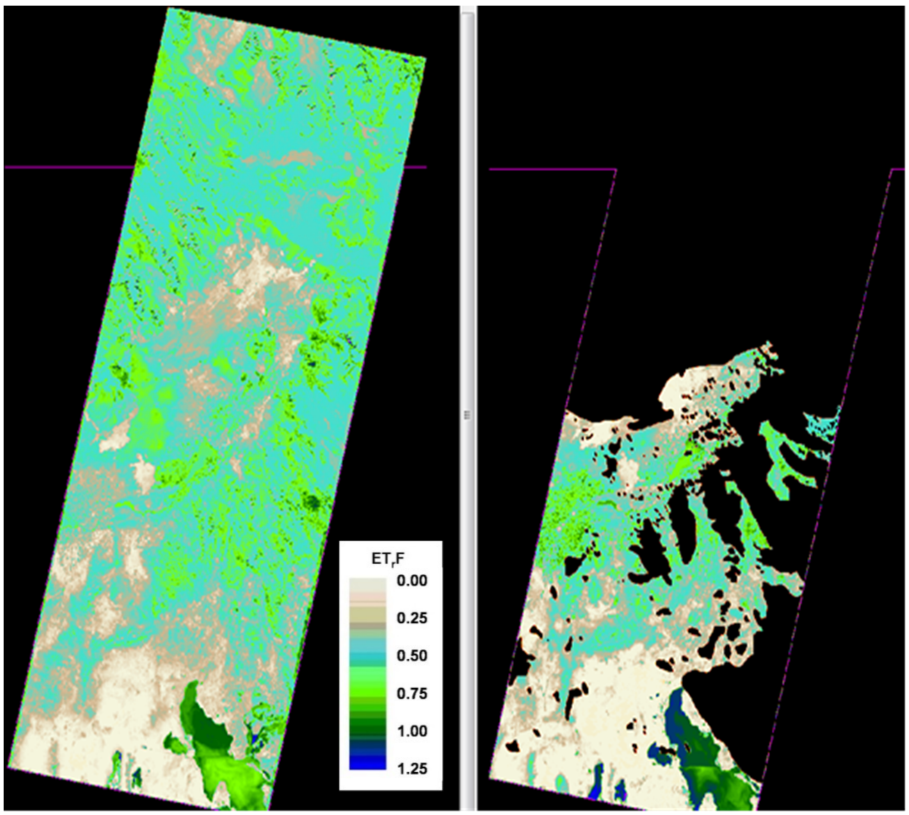


Figure 101. ET_rF map for 3/20/2016 (left) and 4/05/2016 (right) for path 39.

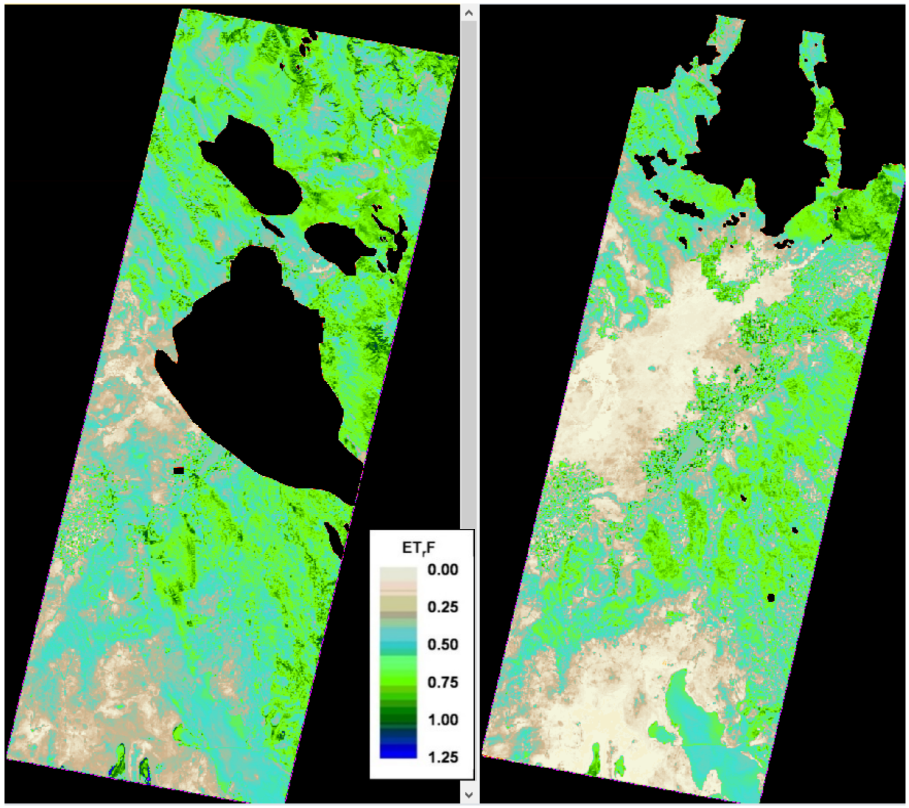


Figure 102. ET$_r$F map for 4/21/2016 (left) and 5/31/2016 (right) for path 39.

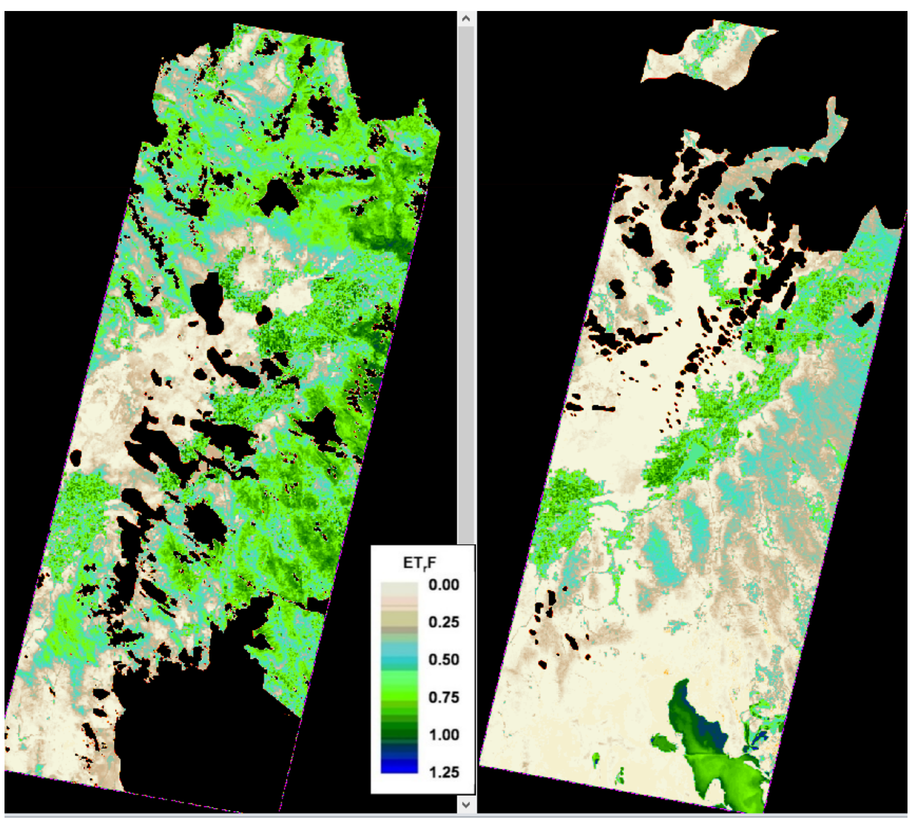


Figure 103. ET$_r$F map for 6/08/2016 (left) and 6/24/2016 (right) for path 39.

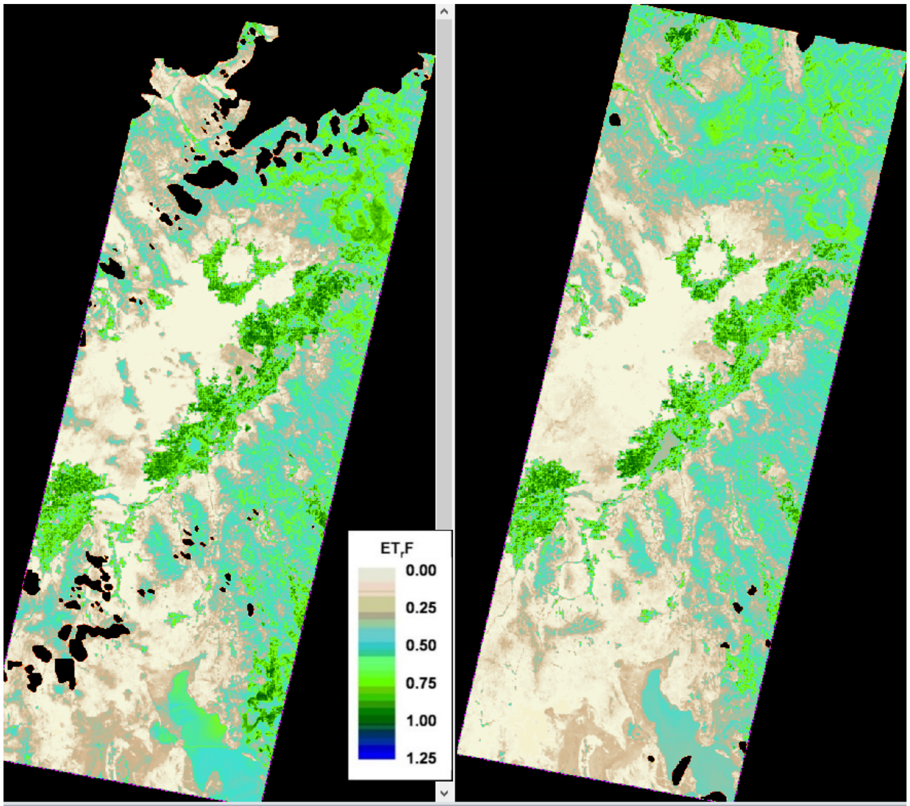


Figure 104. ET$_r$F map for 7/02/2016 (left) and 7/18/2016 (right) for path 39.

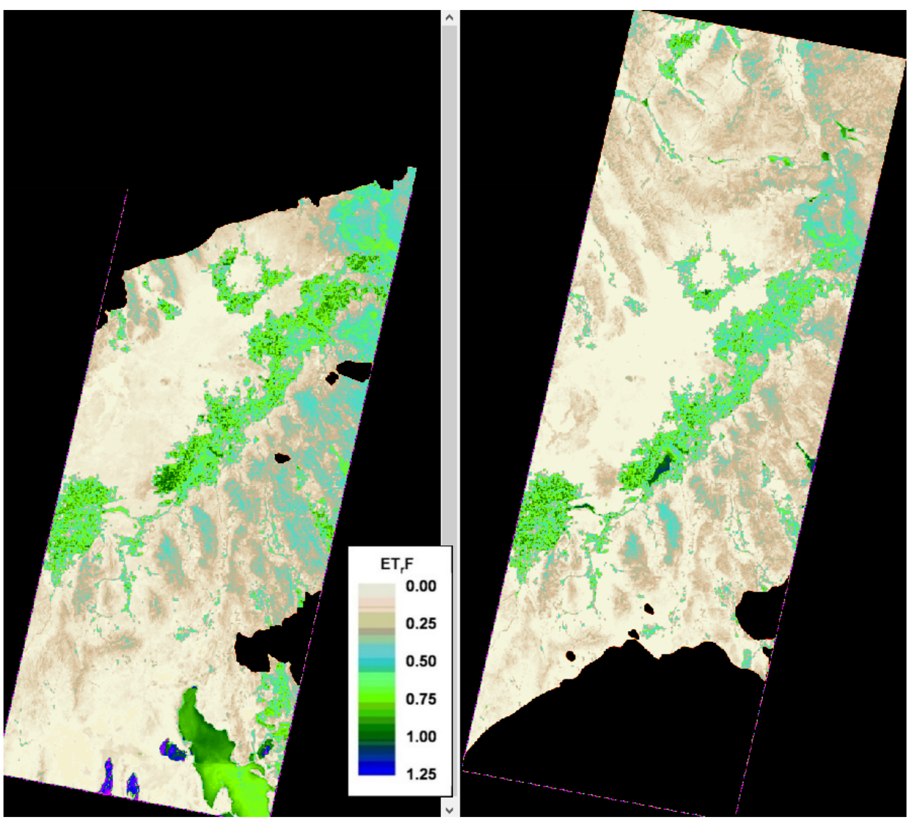


Figure 105. ET$_r$F map for 7/26/2016 (left) and 8/03/2016 (right) for path 39.

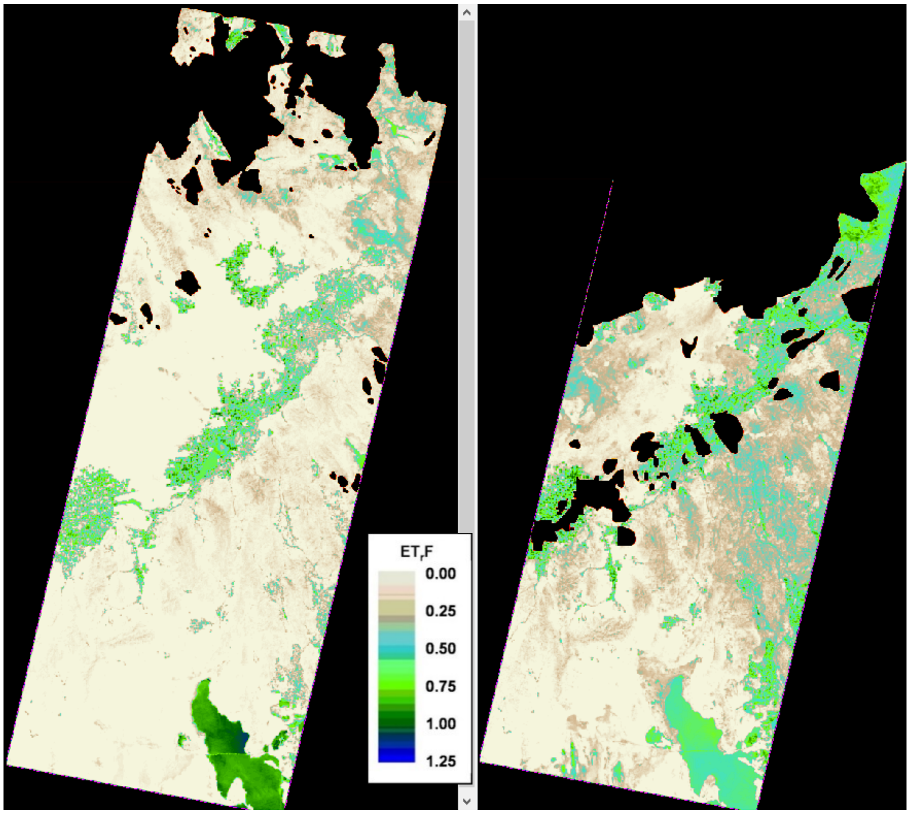


Figure 106. ET$_r$F map for 8/19/2016 (left) and 8/20/2016 (right) for path 39.

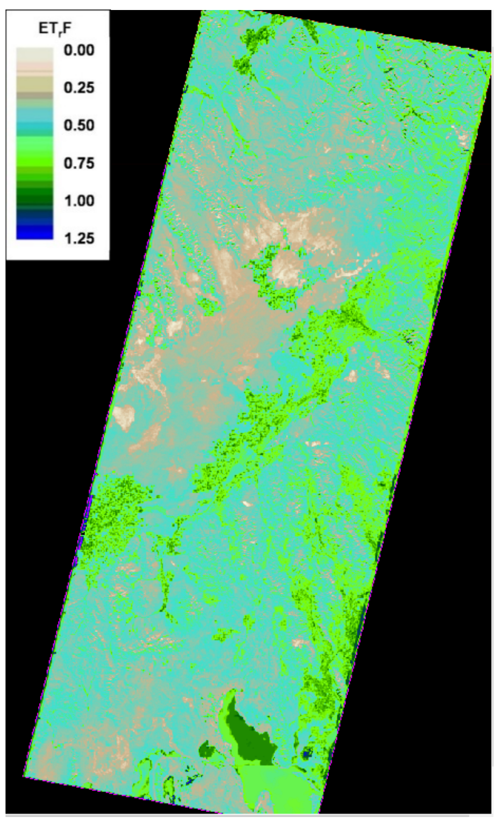


Figure 107. ET$_r$F map for 9/28/2016 for path 39. The image is clear.

Path 40

Daily ETrF maps for path 40 are shown in Figure 108 to Figure 115. ***Masked cloud and shadow areas are shown as black***. The September 27th image was clear, cloud free.

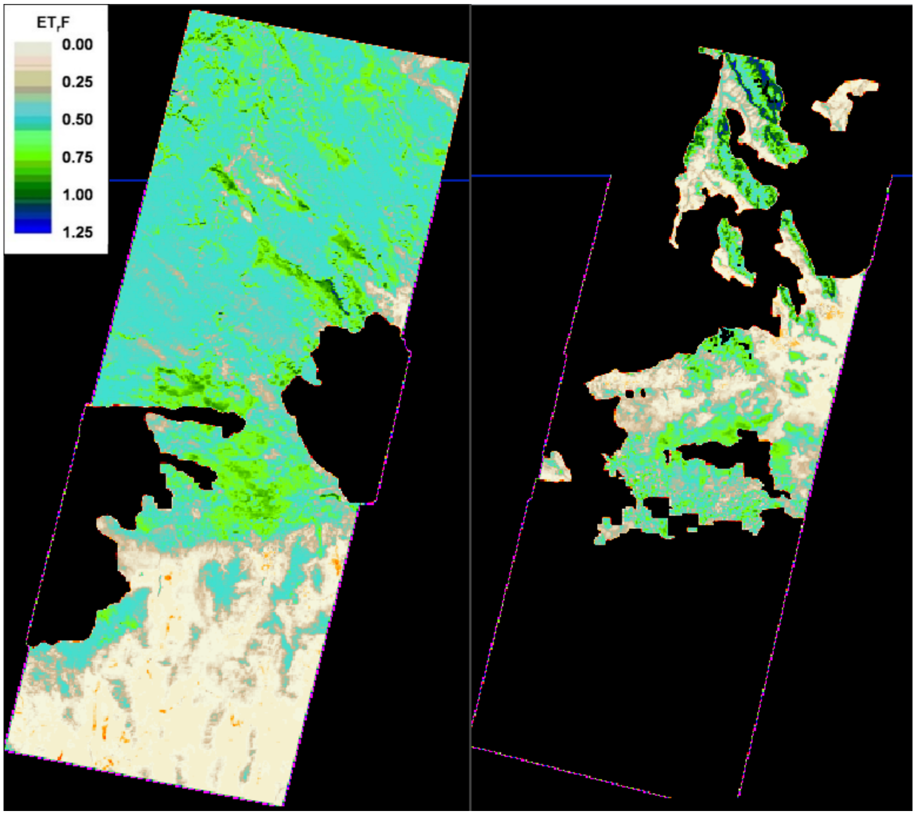


Figure 108. ET_rF map for 3/19/2016 (left) and 4/12/2016 (right) for path 40.

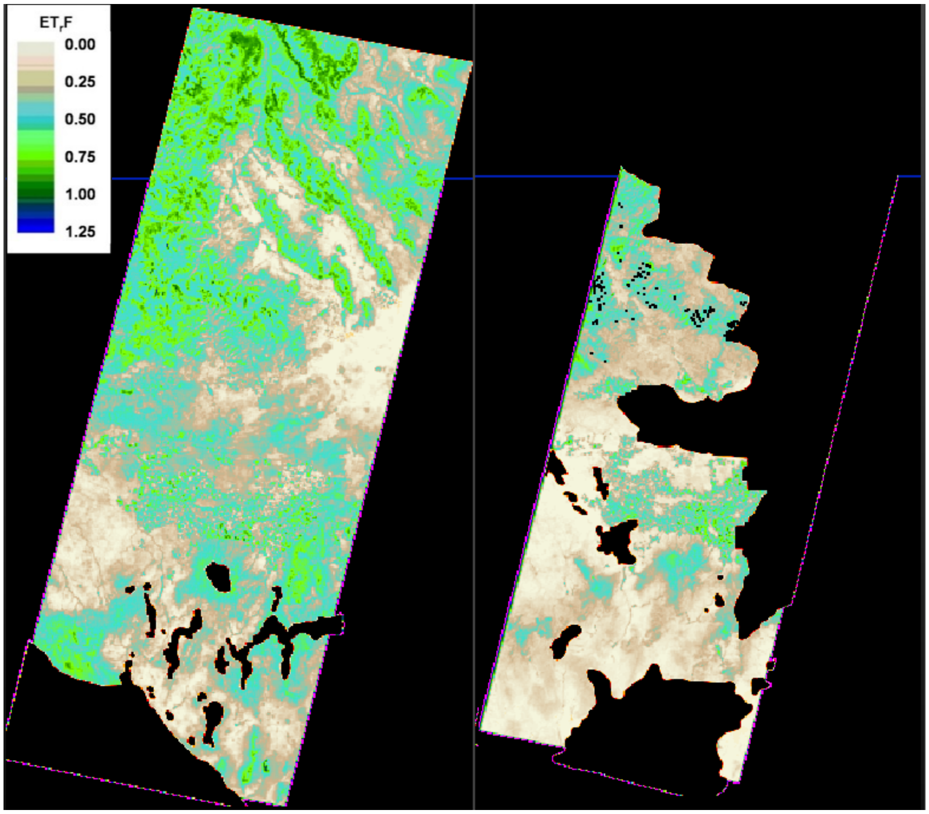


Figure 109. ET$_r$F map for 4/20/2016 (left) and 5/30/2016 (right) for path 40.

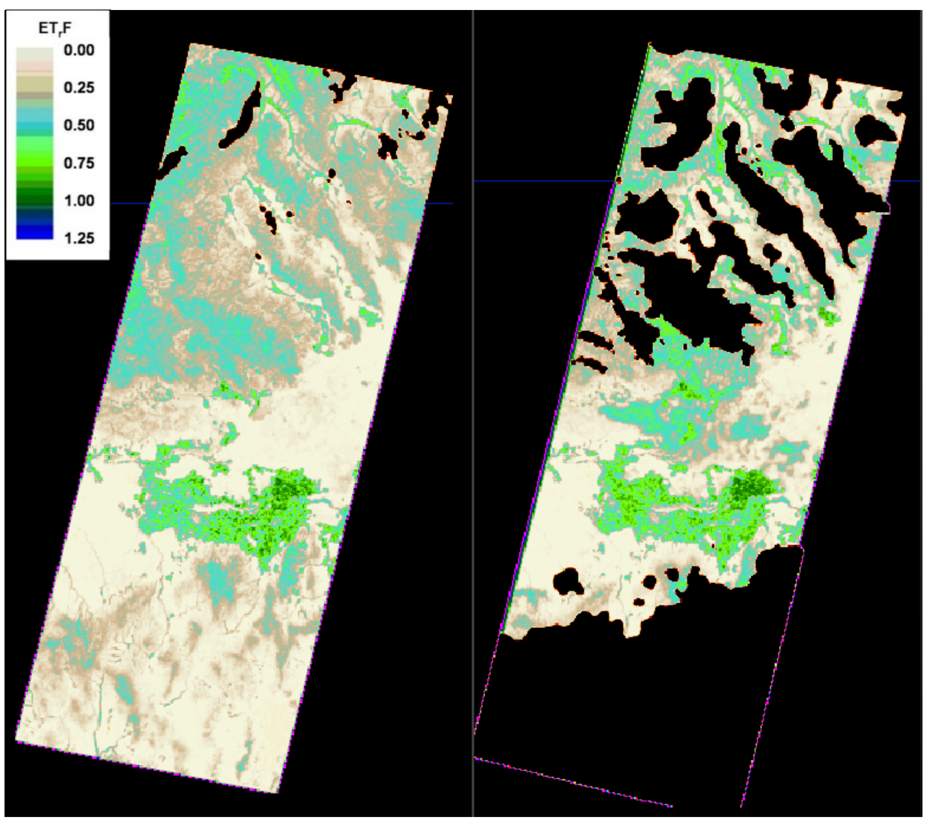


Figure 110. ET$_r$F map for 6/23/2016 (left) and 7/01/2016 (right) for path 40.

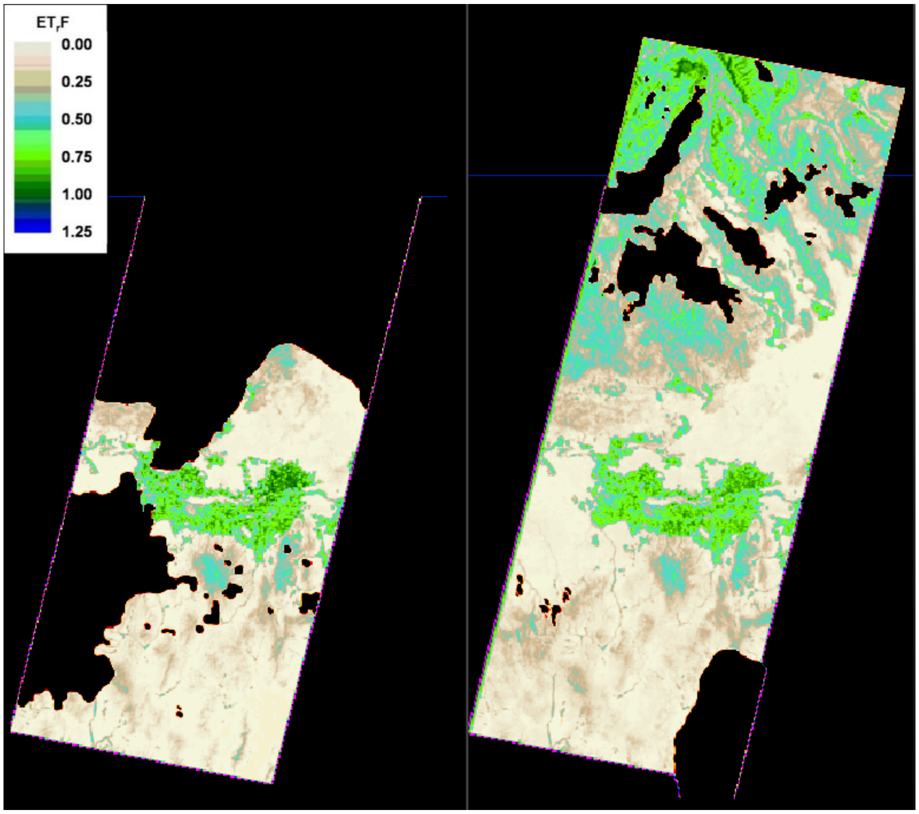


Figure 111. ET_rF map for 7/09/2016 (left) and 7/17/2016 (right) for path 40.

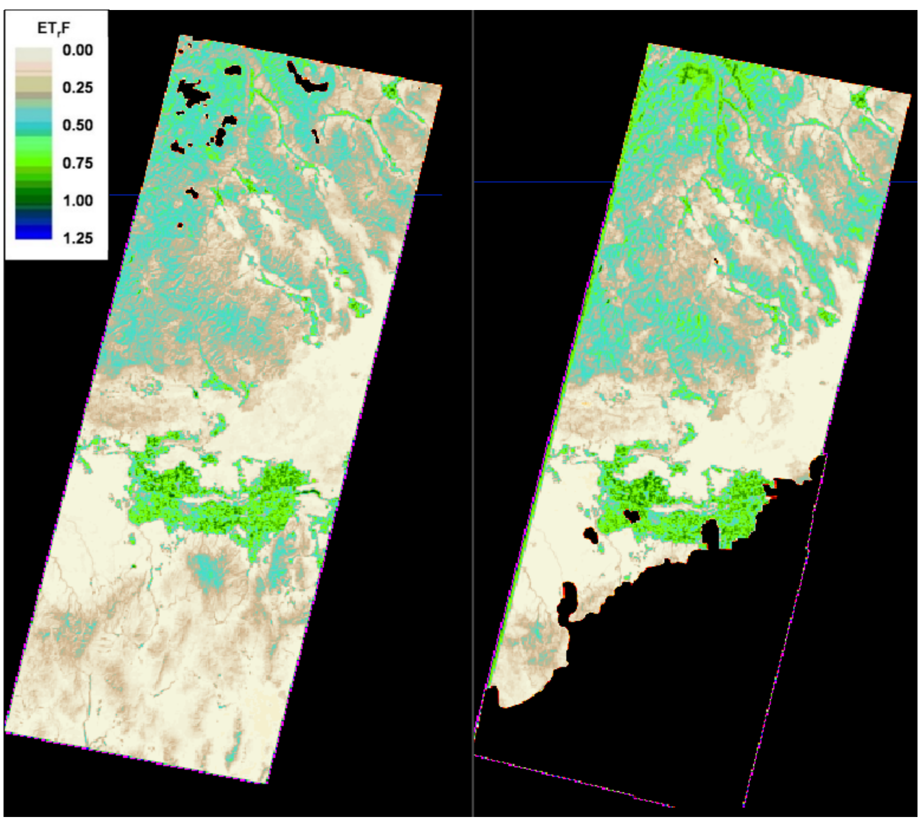


Figure 112. ET_rF map for 7/25/2016 (left) and 8/02/2016 (right) for path 40.

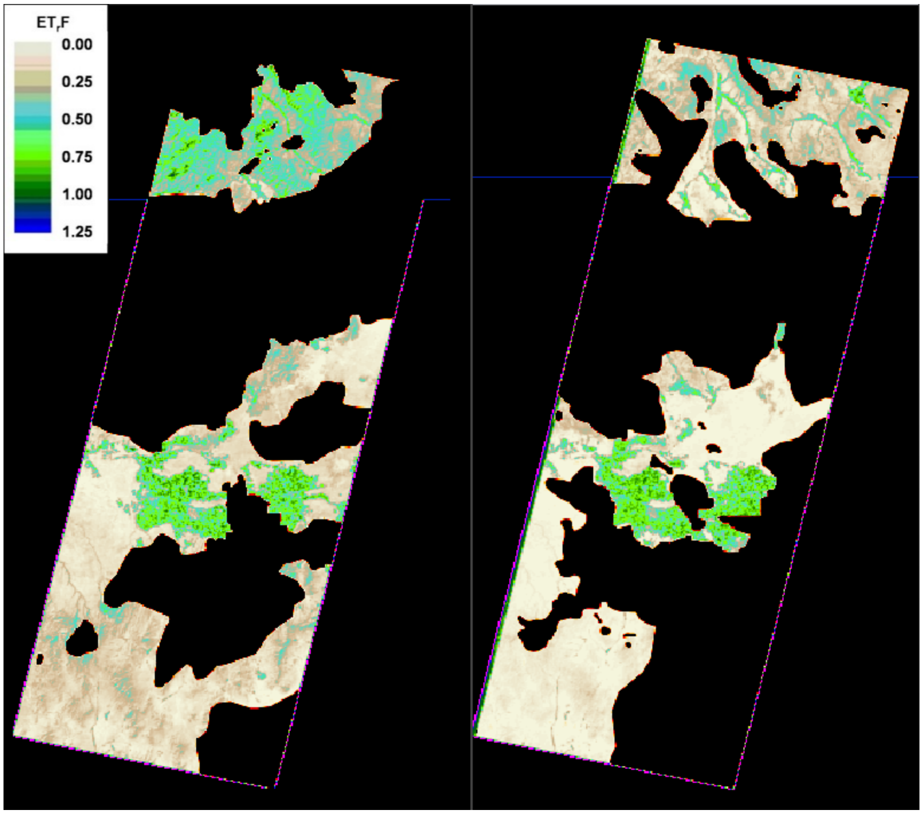


Figure 113. ET$_r$F map for 8/10/2016 (left) and 8/18/2016 (right) for path 40.

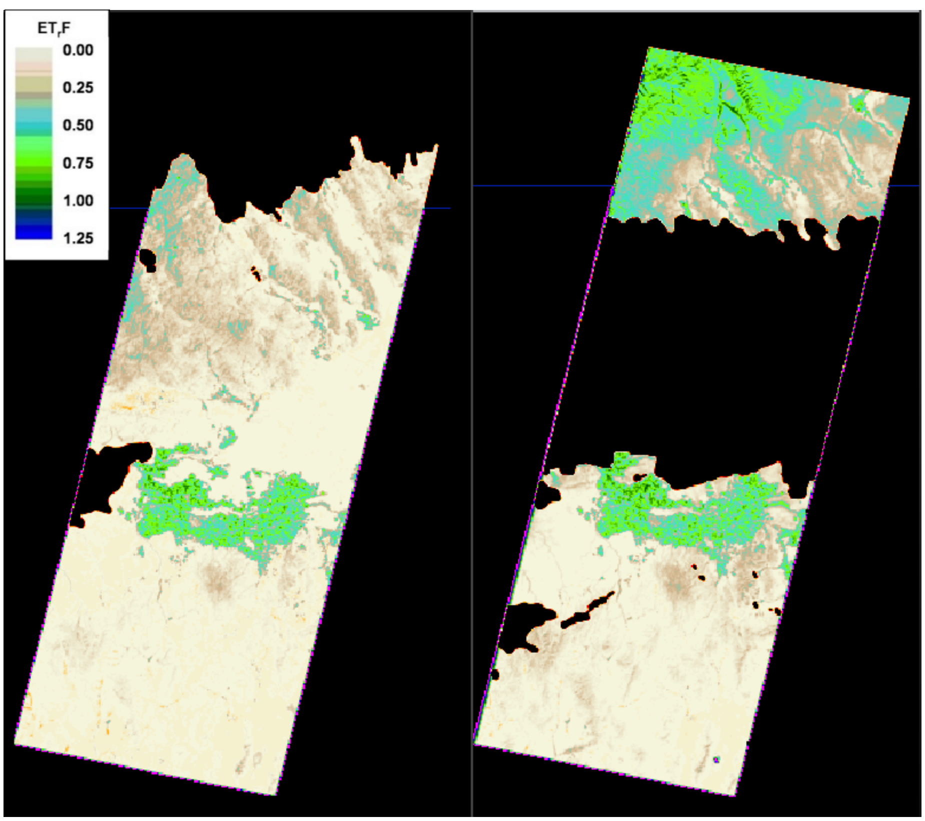


Figure 114. ET$_r$F map for 9/11/2016 (left) and 9/19/2016 (right) for path 40.

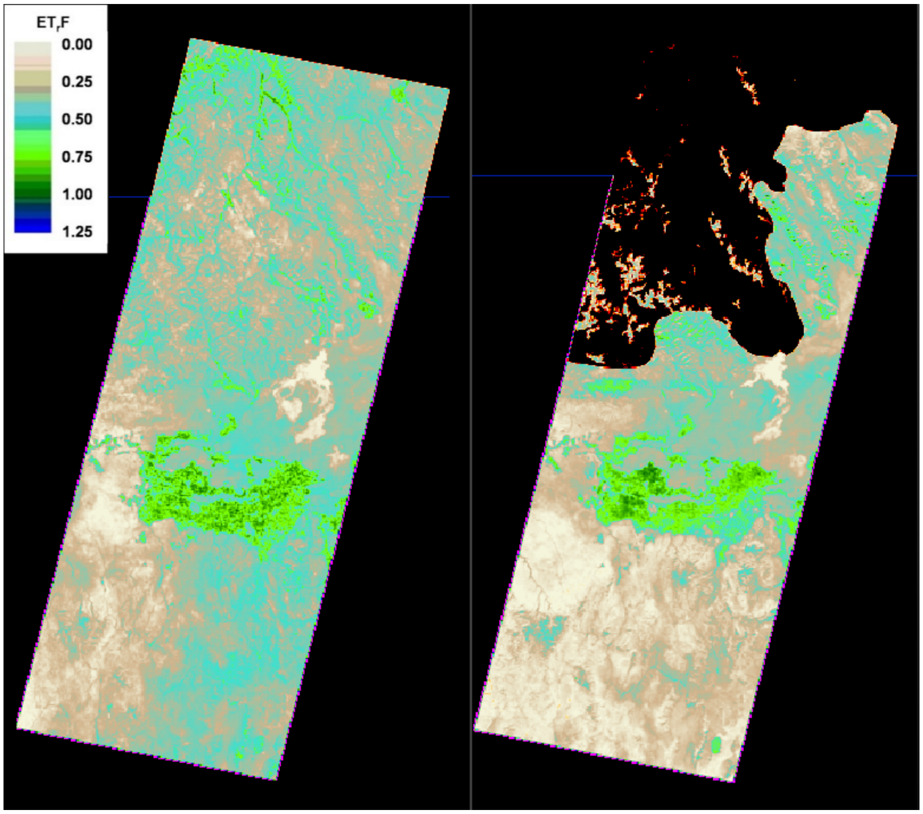


Figure 115. ET_rF map for 9/27/2016 (left, cloud free) and 10/21/2016 (right) for path 40.

Appendix D:
Steps for Stacking, Projecting and Mosaicking EROS Satellite Raster Images for METRIC Processing

Carlos Kelly and Ricardo Trezza, January 2017

METRIC utilizes order specific 7-layer spectral raster image in order to run its models. Table 1 shows the individual spectral bands acquired by both Landsat 7 and 8, respectively, that METRIC uses in its processing. In Idaho, each path/row stacked image needs to be re-projected to IDTM83 as required by IDWR. Finally, each path/rows(s) re-projected image needs to be mosaicked to create a path specific raster image for each satellite date. The ESPA 2016 METRIC application is comprised of paths 40 and 39 where each path contains three rows (29, 30, and 31). Below is a short description of the necessary steps to create a raster image that METRIC utilizes in the generation of ET maps: 1) stacking; 2) re-projection; and 3) mosaicking. These steps ensure that each pixel has the same spatial resolution (30m x 30m), geo-registration, and geo-location. ***(Note: it's assumed that the METRIC operator is familiar with either ArcGIS or ERDAS functions. The terminology for ERDAS might differ from ArcGIS. For example, ERDAS stacking function is called composite band in ArcGIS.)***

Step 1: Stacking the Landsat Images

Landsat images to be used for METRIC processing must be stacked as a seven-layer file arranged in a "**specific order"** (order matters**)**. This order is needed to be an input for METRIC processing. Table 1 shows the exact order of the bands depending on the platform used:

Table 13. Order of the Landsat layers used for METRIC processing

	Description	**Landsat 5**	**Landsat 7**	**Landsat 8**
Layer 1	*Visible(blue)*	Band 1	Band 1	Band 2
Layer 2	*Visible (green)*	Band 2	Band 2	Band 3
Layer 3	*Visible (red)*	Band 3	Band 3	Band 4
Layer 4	*Near Infrared*	Band 4	Band 4	Band 5
Layer 5	*SWIR – 1*	Band 5	Band 5	Band 6
Layer 6	*Thermal*	Band 6	Band 6_1 (low gain)	Band 10
Layer 7	*SWIR – 2*	Band 7	Band 7	Band 7

SWIR = Short Wave Infrared

The stacking process can be performed in ERDAS using the function: **RASTER → Spectral → Layer stack**

Step 2. Projection of the stacked images to Idaho Transverse Mercator (IDTM83)

Original Landsat images from USGS come in a UTM projection. For METRIC processing in Idaho applications, these stacked images must be re-projected to IDTM83. Figure 116 shows the attributes of IDTM83. Re-projection of the images is performed using the ERDAS re-projection tool. The characteristics of the IDTM83 projection can be seen in the image metadata, after re-projection is completed:

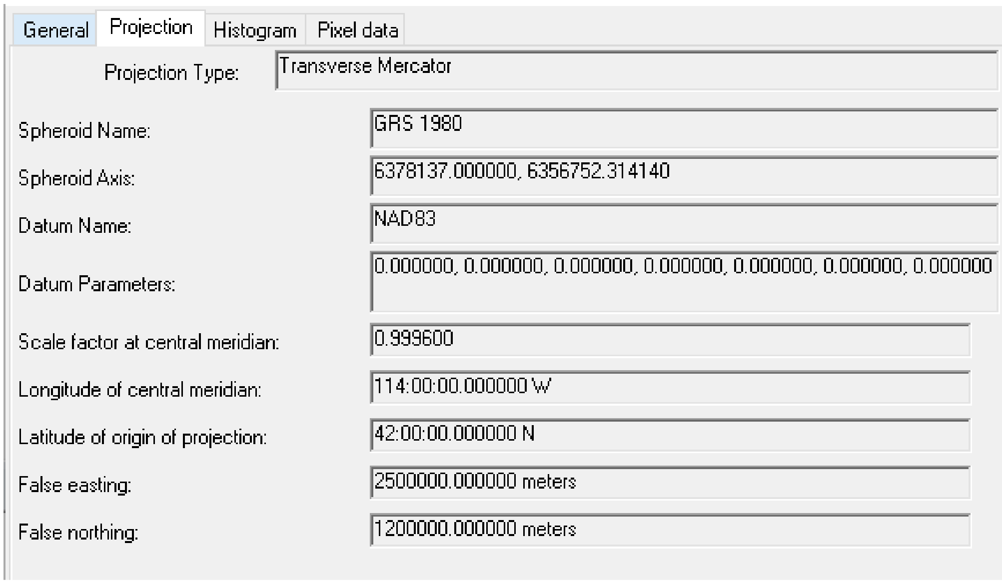


Figure 116. General attributes of the IDTM83 geographic projection.

Once ERDAS is opened, go to **RASTER → Re-project** and choose the following in the "Re-project Images" window. Pay close attention to dialog box shown in Figure 117 specifically the contents of red boxes:

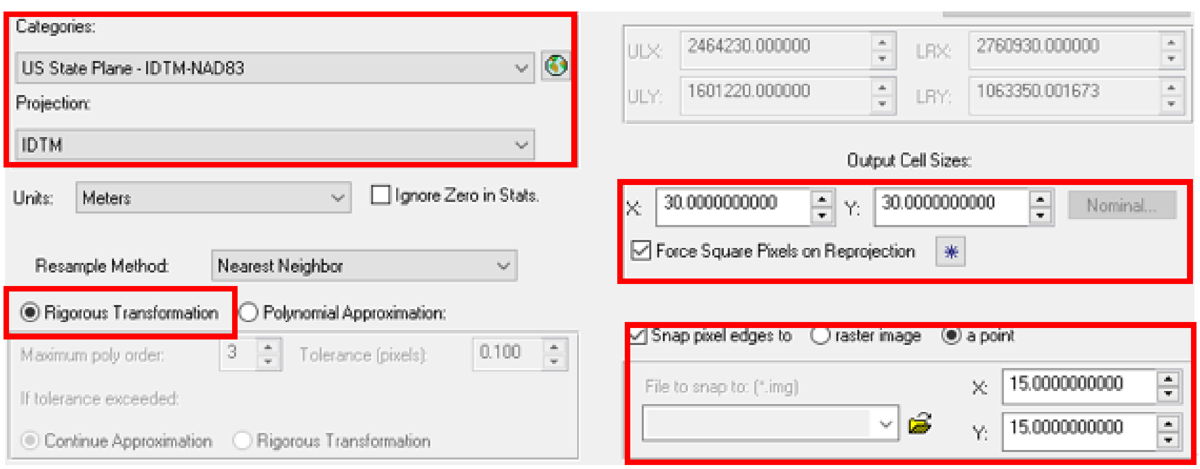


Figure 117. Re-projecting Landsat images to IDTM using ERDAS

Step 3: Mosaicking Images

Upon re-projection to IDTM83, the images (different rows for the same date and path) can be mosaicked using the ERDAS mosaic tool: **RASTER → Mosaic.**

The images to mosaic, for example row 29, 30, and 31 for Path 39 are added to the mosaic tool window. Then, in the mosaic window, go to: **PROCESS → Run mosaic**